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DSTO

Colours of Northern Australia: Visible and Near-IR Reflectance of Natural Terrain Elements

Russell J. Boyd

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Land, Space and Optoelectronics Division
Electronics and Surveillance Research Laboratory

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ABSTRACT

A major requirement of the systematic design of camouflage is to obtain a colorimetric match of the camouflaged object to its anticipated surroundings. This match needs to cover both the visible and, because of the operating bands of silicon based surveillance sensors such as image intensifiers and low light TV, the near-infrared. This report presents spectral reflectances and CIE colour co-ordinates of natural terrain elements in the visible and near-infrared wavelengths (380 - 1800nm). Measurement sites range from Townsville to Tom Price across northern Australia. Complete data sets are available as Microsoft Excel spreadsheets and charts.

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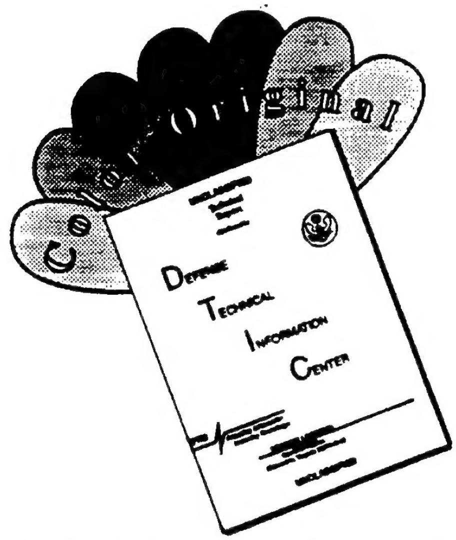

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Colours of Northern Australia: Visible and Near-IR Reflectance of Natural Terrain Elements

EXECUTIVE SUMMARY

A major requirement of the systematic design of camouflage is to obtain a colour match of the camouflaged object to its anticipated surroundings. This match needs to cover both the visible and, because of the operating bands of image intensifiers and low light TV, the near-infrared.

Sites were chosen across northern Australia where colour measurements could be made of typical terrain and foliage. It is necessary to conduct these measurements in the field since any attempt to bring samples into the laboratory changes the nature of the sample or changes its appearance from those encountered in natural ambient conditions. In the case of many native Australian flora a measurable change in both colour and near infrared reflectance may be observed within hours of removal from the parent plant. It is also rare that the colour of a leaf is a representative measure of the general colour of the tree since things such as gloss, self shading, variation of leaf colour, foliage density and dust all have a measurable effect. In the case of soils, moisture content and particle size will affect not only the colour but the shading.

A field telespectrophotometer (TSP) was developed to perform these measurements by comparing the amount of light reflected from the terrain through each waveband (blue, green, red, near-infrared) with a known white standard. The 2° field of view of the TSP enabled measurements to be taken of a few leaves or blades of grass at a viewing distance of 3 to 4m, or of entire trees or forest canopies at ranges of several hundred metres. The samples measured were typical trees, grasses and bare soil and the survey was conducted in two phases in order to capture the extremes of colour variation over the monsoonal wet season and the mid year "dry".

Results are presented as spectral reflectance curves and colour co-ordinates in the international CIE system. All data are available in spreadsheets for Microsoft Excel, (version 4). A reduction of this data by averaging across all locations for each major sample type and season produces two groups of curves which may be considered typical of colours of northern Australian terrain and which may be chosen for camouflage purposes as being least likely to be a significant mismatch to the background.

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Russell Boyd is a graduate of the Footscray Institute of Technology where he obtained a Diploma of Electronic Engineering. He began work at DSTO in Melbourne in 1970 and in 1975 joined the Optics Group to work on the development of colour measurement instrumentation, with particular application to camouflage. Following extensive experience in the design and testing of camouflage materiel he transferred in 1989 to Surveillance Research Laboratory, Salisbury, to manage a passive countersurveillance task.

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Contents

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1. Introduction

A major requirement of the systematic design of camouflage is to obtain a colorimetric match of the camouflaged object to its anticipated surroundings. This match needs to cover both the visible and, because of the operating bands of silicon based surveillance sensors such as Image Intensifiers and Low Light TV, the near-infrared. A survey was therefore carried out using a field telespectrophotometer (TSP), described later in the text, to gather spectral reflectance data of natural terrain elements in Northern Australia in the wavelength band 380 to 1800nm. The CIE (Commission Internationale d'Eclairage) colour co-ordinates were calculated using a subset of these reflectance values.

Following a preliminary survey the sites chosen were Townsville and Cairns in Queensland, Darwin and Katherine in the Northern Territory, and Derby and Tom Price in Western Australia.

This report documents the survey, instrumentation and methodology and presents results in a form accessible to potential users.

2. Instrumentation

2.1. Telespectrophotometer

The instrument [1] was built as a prototype at the Materials Research Laboratories, (now Aeronautical and Maritime Research Laboratory) DSTO Melbourne. It consists of dual beam optics with a chopper to alternate both sample and reference light beams through a pair of monochromators. The sample/reference ratio is measured using a photomultiplier tube in the 380 to 880nm band and a Peltier-cooled PbS detector for the 800 to 1800nm band. Control and data recording are performed by a purpose built controller using an Intel 8080 processor and an Analog Devices 12-bit A-D card in an SBC bus. All measurement and data storage functions are controlled by a series of switches, rather than keyboard control, the control program being about 60kBytes of 8080 assembler code.

Output from this instrument is in terms of reflectance ratios of the measured sample against a standard at 5nm intervals in the range 380 to 880nm, and at 10nm intervals in the range 800 to 1800nm. Bandwidth of measurements is determined by the slit width at the input port of the monochromators, and was 2nm in the visible and 4nm in the near-IR. There is a gap in the data in the 1370 to 1450nm region where water vapour in the atmosphere effectively blocks all transmission; reflectances measured in this region are consequently noisy and unreliable. The water vapour absorption renders this band inherently irrelevant to surveillance.

The raw instrumental data (reflectance ratios) are stored on a digital audio cassette in a format particular to the controller hardware, then transferred to another computer system for further processing. This involves conversion to absolute reflectance spectra, based on the laboratory measured reflectance of the white standard used in the field, and then calculation of CIE colour co-ordinates.

2.2 White Reference

Since the telespectrophotometer is a ratio device, a white panel is required as a reflectance reference, placed in similar lighting to the sample under consideration. A board was produced using Barium Sulphate ($BaSO_4$), a standard white reference material with a relatively flat reflectance in the region of interest, as shown at Figure 1. The barium sulphate was applied as a suspension in a water-alcohol solvent over an undercoat of white paint, using a spray painting unit to give a thick, matt coating. To enable its use as a standard the absolute reflectance was determined using measurements from a Cary 14 laboratory spectrophotometer with a specially constructed barium sulphate coated integrating sphere. The absolute reflectance measurement methodology is described at [2].

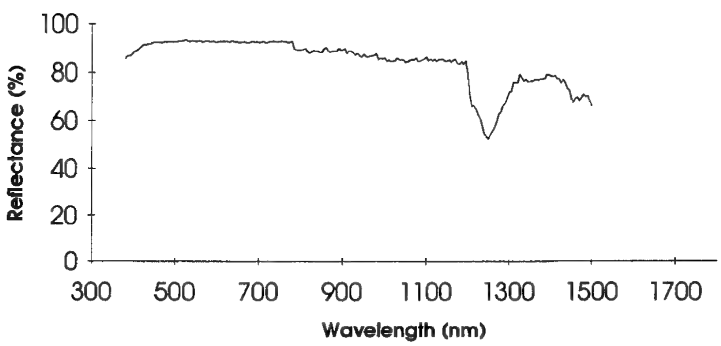

Figure 1. Reflectance of Barium Sulphate 'standard white'

3. Methodology

3.1 Measurements

The 2° field of view of the TSP enabled measurements to be taken of a few leaves or blades of grass at a viewing distance of 3 to 4m, or of entire trees or forest canopies at ranges of several hundred metres. The samples measured were typical trees, grasses and bare soil. Measurements were constrained by possible fields of view and the ability to isolate a particular sample from its surroundings. This sample may typically have been represented by a single tree with no included background, either sky or ground, or an area of soil unobscured by grasses. In general the area of any trees measured was about 1 square metre, however on some occasions it was possible to view an entire foliage canopy in isolation which may represent an area of 10x10m. Grasses were usually viewed at a range of about 20m allowing a full coverage with no

voids. Soils were measured at closer ranges, due to the need to find bare unobscured patches, resulting in a sample size of approximately 50x50cm.

The choice of what may be considered typical for any given area was made by a civilian, non-botanical scientist. Having driven considerable distances through each area in search of suitable sites it was relatively easy to choose samples typical to the area.

Given the limitations of measurement and setup time, typically 5 minutes for each sample, sites were chosen which afforded a view of a variety of representative natural terrain elements typical of the locality. The white reference was placed in the field of view of one telescope in such a way as to be similarly lit as the terrain sample under consideration and at an angle determined to avoid specular reflection of sunlight.

It is necessary to conduct these measurements in the field since any attempt to bring samples into the laboratory changes the nature of the sample or changes its appearance from those encountered in natural ambient conditions. In the case of many native Australian flora a measurable change in both colour and near infrared reflectance may be observed within hours of removal from the parent plant. It is also rare that the colour of a leaf is a representative measure of the general colour of the tree since things such as gloss, self shading, variation of leaf colour either within the leaf or from top to bottom, foliage density and dust all have a measurable effect. In the case of soils, moisture content and particle size will affect not only the colour but the shading, hence a sample prepared for laboratory measurement may not accurately represent the appearance in the field.

3.2 Seasonal variation

In order to capture the extremes of colour variation, the survey was conducted in two phases over March-April and September-October of 1983. March is approaching the end of "the wet" in northern Australia and consequently is a time when most plant growth is at its greenest. October is at the end of "the dry", a period of effectively zero rainfall over 3 months for most sites, and the ideal time for dry season measurements. These times were chosen from Bureau of Meteorology climatic averages (calculated over 10 years) and the conditions encountered at the time did not significantly vary from published averages.

3.3 Locations

Following an initial survey by DSTO and Army personnel, sites were chosen as being typical of the various regions of northern Australia and of relevance to the ADF. These were Darwin and Katherine in the Northern Territory, Derby and Tom Price in Western Australia and Townsville and Cairns in Queensland. Measurement sites were chosen within 50km of these centres.

4. Results

All spectral and co-ordinate data are available in spreadsheets for Microsoft Excel, (version 4). Absolute reflectance spectra are given for each measurement made. See Appendix 2 for details.

4.1 Colour Co-ordinates

Individual colours are defined in the CIE system [3]. Colour co-ordinates x,y,Y and L*,a*,b* for Illuminant D65 are calculated from a reflectance spectrum in the range 380 to 780nm as described in Appendix 1. The CIE 1976 (L* a* b*) colour space (CIELAB) is used as the best approximation to a uniform colour space for surface colours. 1 CIELAB unit is the nominal threshold for visually discernible colour difference. [4]

An "average" colour has been calculated from the average reflectance at each wavelength of all samples in each location/sample/season group. These results are presented in Table 1. This average is presented as a guide only to typical colours and does not necessarily represent the dominant colour of the region. Calculation of the average by this method varies only very slightly from a simple average of the CIELAB co-ordinates. This variation is generally below 5% of the value calculated and results in a total colour difference of less than 1 CIELAB unit.

4.2 Spectral Reflectance

Spectral reflectance plots in the range 380 to 1800 nm are shown at Figures 2 to 8. Data are grouped according to location, sample type and season, as shown at Table 2. While there is no current surveillance requirement for data in the 1100 to 1800 nm band, based on the lack of sensors operating in this region, the possible measurement band was defined by the instrumental design. This information is presented in anticipation of some future requirement.

The heavy line shown on each plot is the average of all samples in each group, included as an indication of what may be considered typical. These averages are displayed at Figure 9. A further reduction of this data by averaging across all locations for each major sample type and season is shown at Figure 10. This clearly shows two groups of curves. While this method of averaging spectra is not rigorous in terms of the number of samples in each set or the similarity of samples measured over different seasons, it does give an indication of colours which may be chosen for camouflage purposes as being least likely to be a significant mismatch to the background colours over large tracts of northern Australia.

Table 1. Colour co-ordinates in CIE Lab space. The values shown are the average of all measurements taken in each grouping.

Sample	Location	Wet Season			Dry Season		
		L*	a*	b*	L*	a*	b*
Grass	Townsville	45.82	- 4.75	20.44	50.79	2.49	15.03
	Cairns	36.20	- 7.38	20.93	44.60	- 0.03	16.49
	Darwin	45.53	- 3.01	22.89	42.91	4.32	17.00
	Katherine	39.23	- 3.31	19.87	52.61	5.65	20.09
	Derby	45.78	- 3.56	17.82	52.81	5.05	23.09
	Tom Price	48.59	0.86	20.97	54.15	2.99	21.95
Trees	Townsville	38.04	- 4.69	13.70	39.27	- 2.81	13.99
	Cairns	35.23	- 5.43	18.08	39.38	- 1.60	11.64
	Darwin	42.59	- 4.30	11.05	39.91	- 4.94	21.17
	Katherine	34.37	- 5.56	13.82	45.59	- 1.62	15.37
	Derby	37.27	- 4.97	15.22	44.49	- 2.69	17.10
	Tom Price	47.97	1.10	12.93	39.71	- 0.42	15.08
Soil	Townsville	58.66	6.88	16.91	43.06	2.63	11.51
	Cairns	40.41	2.99	16.82	59.05	10.60	26.78
	Darwin	53.00	11.81	17.61	49.32	10.46	18.05
	Katherine	50.35	7.70	15.61	53.06	8.17	17.57
	Derby	54.13	16.80	22.11	58.50	17.47	25.16
	Tom Price	46.02	11.93	13.88	43.15	15.49	18.90
Sugar Cane	Cairns	44.74	- 7.43	10.00	54.09	- 4.66	23.22
Tree Trunk	Townsville	26.62	- 0.70	7.97			
Scrub	Townsville	43.67	- 7.05	20.70			

***Table 2.** Description of available spectral plots.*

Sample type	Wet Season	Dry Season
Grass	Figure 2.1 - 2.6	Figure 3.1 - 3.6
Soil	Figure 4.1 - 4.6	Figure 5.1 - 5.6
Trees	Figure 6.1 - 6.6	Figure 7.1 - 7.6
Scrub	Figure 8.1	
Tree trunk	Figure 8.2	
Sugar cane	Figure 8.3	Figure 8.4
Averages	Figures 9 - 10	Figures 9 - 10

Table 3 shows CIE co-ordinates calculated from the averaged data shown at Figure 10, along with colours chosen for use on Army vehicles in northern Australia. The green is the standard military Bronze Olive and the tan was chosen from a selection of available standard paint colours as being closest to the desired colour. These paint colours vary from the calculated averages by less than 8 CIELAB units, an indication that they are suitable for use over a wide area of northern Australia.

Since data obtained from the PbS detector are often noisy, a simple smoothing has been applied to points in the 800 to 1800nm region for the purpose of graphical representation, resulting in a much less confusing presentation of multiple spectra. Smoothing was achieved with a weighted mean of 7 points, by replacing the value R_n with the value $\overline{R}_n$, at the abscissa n, using the smoothing formula

$$\overline{R}_n = [R_n + 0.5(R_{n+1} + R_{n-1}) + 0.25(R_{n+2} + R_{n-2}) + 0.125(R_{n+3} + R_{n-3})] / 2.75$$

5. Conclusion

As expected the greatest variation in colours occurs within the soils subset. The limited number of samples makes any prediction based on season or location difficult. For the vegetation samples there is an obvious seasonal difference with grasses but little variation for the trees. Variations within each group give an indication of the range of reflectances expected within any waveband and offer valuable data for performance prediction for, for example, night vision instruments, multispectral imagery or vegetation mapping. These variations are typically 15% in the green band and 30% in the near IR at 1000nm.

In camouflage design the requirement for absolute colour matching is not paramount, especially for mobile equipment. It is necessary to have strong contrast for disruptive pattern design and minimal brightness contrast to the background. It is therefore essential to have a knowledge of the range of colours from which to choose those which will least often be a mismatch to the surroundings. This database provides adequate information on the range of colours most likely to be found in northern Australia and on the range and seasonal variation of reflectance values which may be expected within specific wavebands.

6. Acknowledgements

The author wishes to acknowledge the assistance during field measurements from John Russell, Alan Leverett, Ron Steinwall and Lynette Millist, and from Tom Whitehouse for programming initial raw data conversions and colour co-ordinate calculations.

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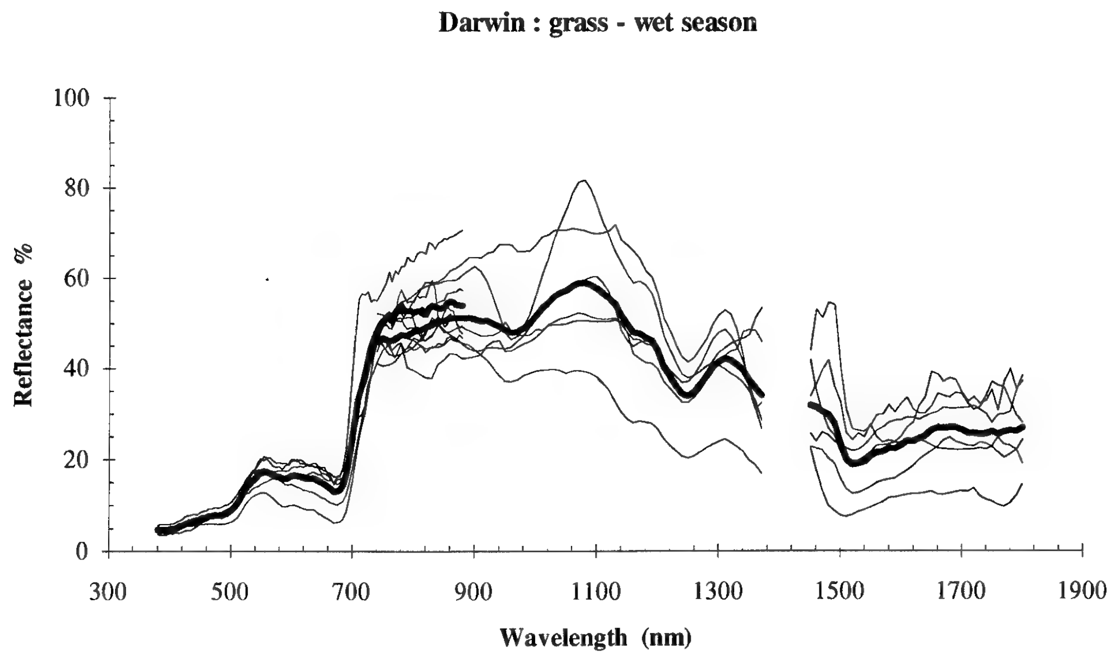


Figure 2.1 Measured reflectances of grasses in the Darwin area, NT, wet season, March 1983. The heavy line indicates the average reflectance.

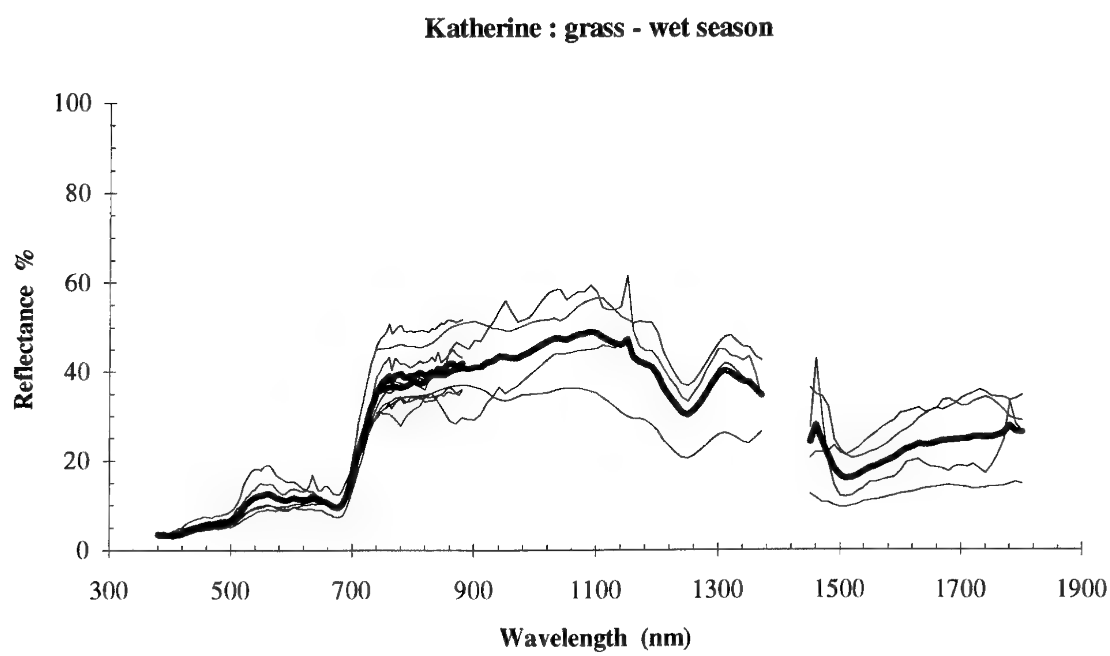


Figure 2.2 Measured reflectances of grasses in the Katherine area, NT, wet season, March 1983. The heavy line indicates the average reflectance.

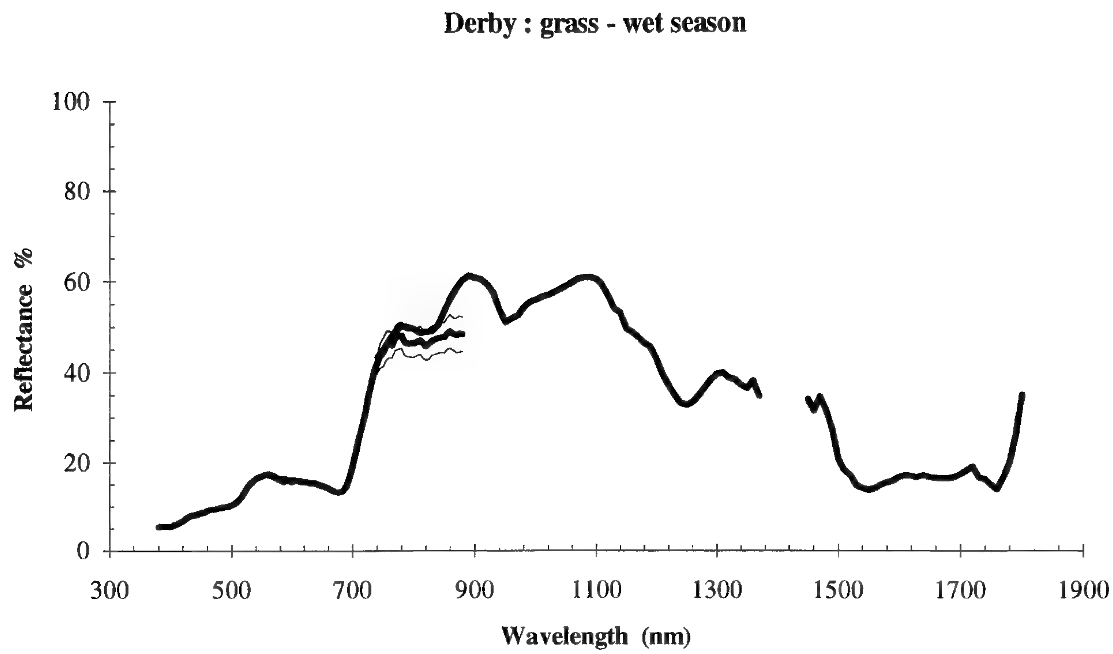


Figure 2.3 Measured reflectances of grasses in the Derby area, WA, wet season, March 1983. The heavy line indicates the average reflectance.

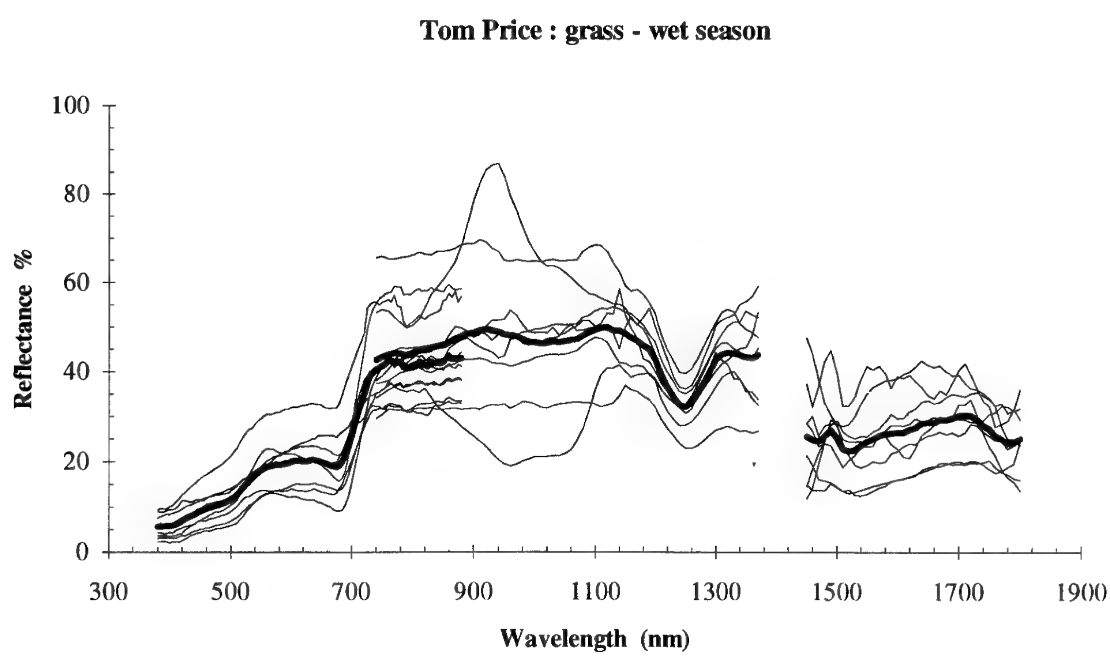


Figure 2.4 Measured reflectances of grasses in the Tom Price area, WA, wet season, March 1983. The heavy line indicates the average reflectance.

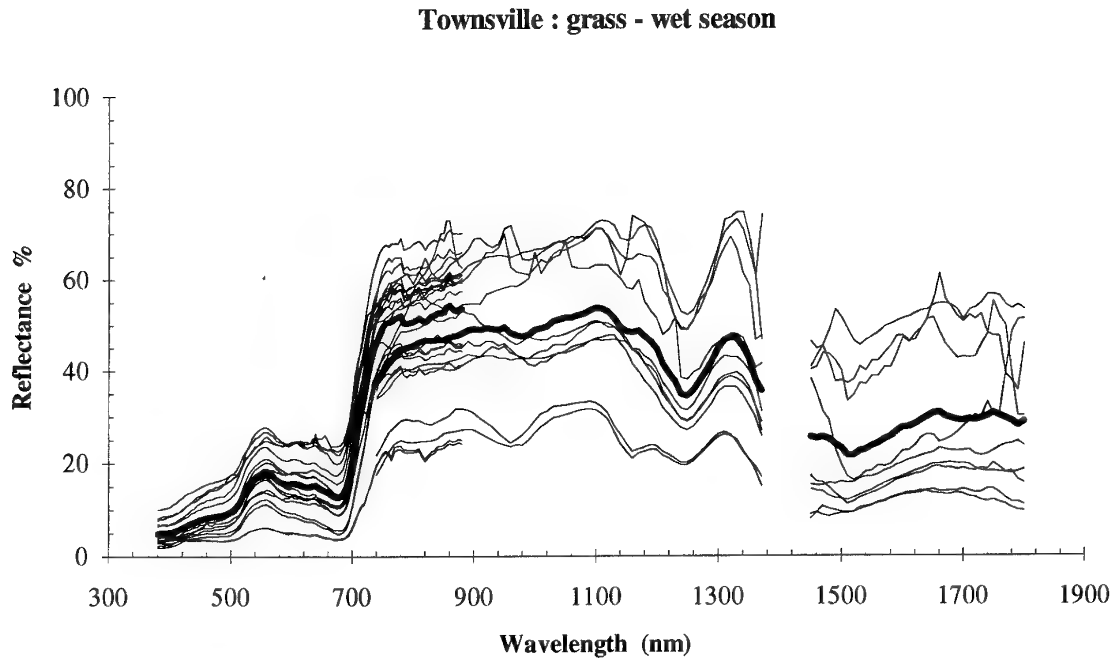


Figure 2.5 Measured reflectances of grasses in the Townsville area, Qld, wet season, April 1983. The heavy line indicates the average reflectance.

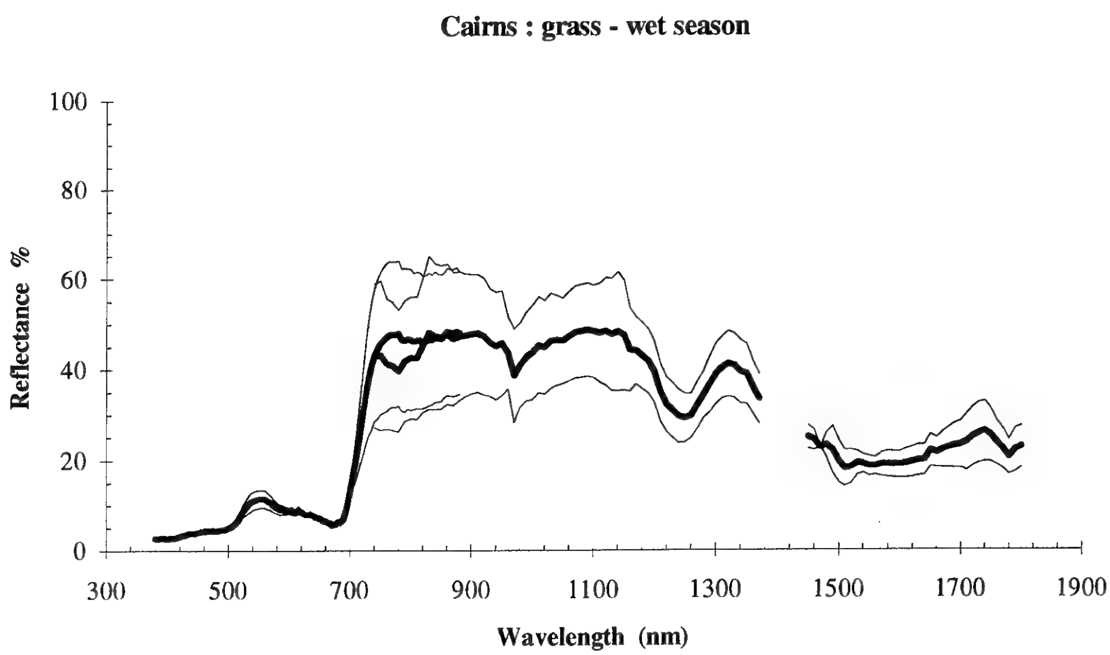


Figure 2.6 Measured reflectances of grasses in the Cairns area, Qld, wet season, April 1983. The heavy line indicates the average reflectance.

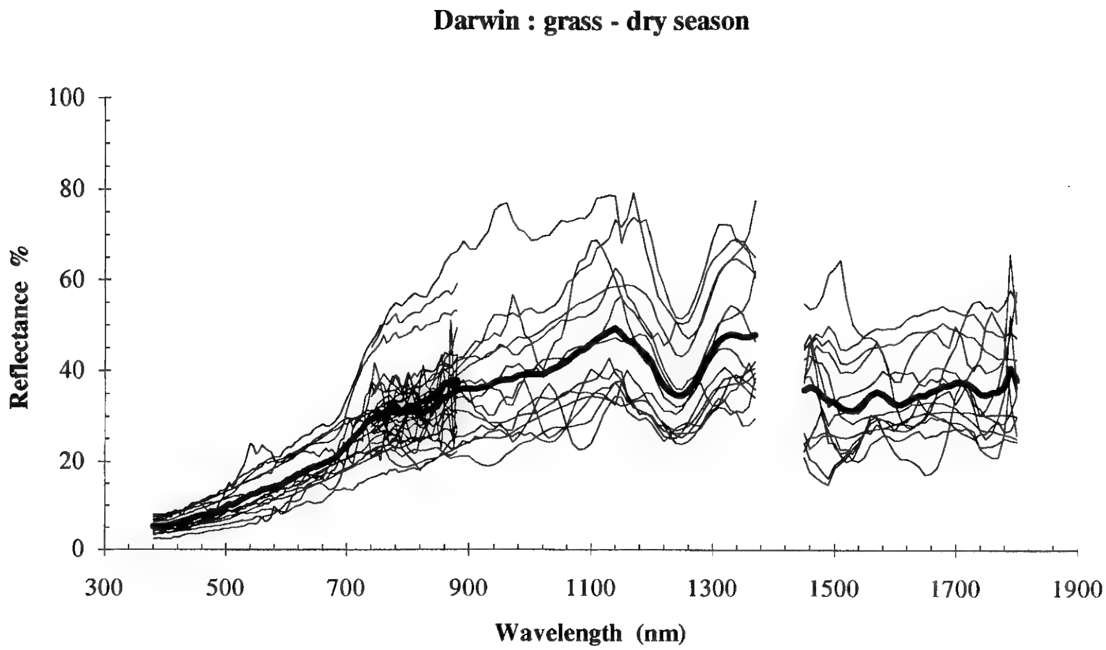


Figure 3.1 Measured reflectances of grasses in the Darwin area, NT, dry season, March 1983. The heavy line indicates the average reflectance.

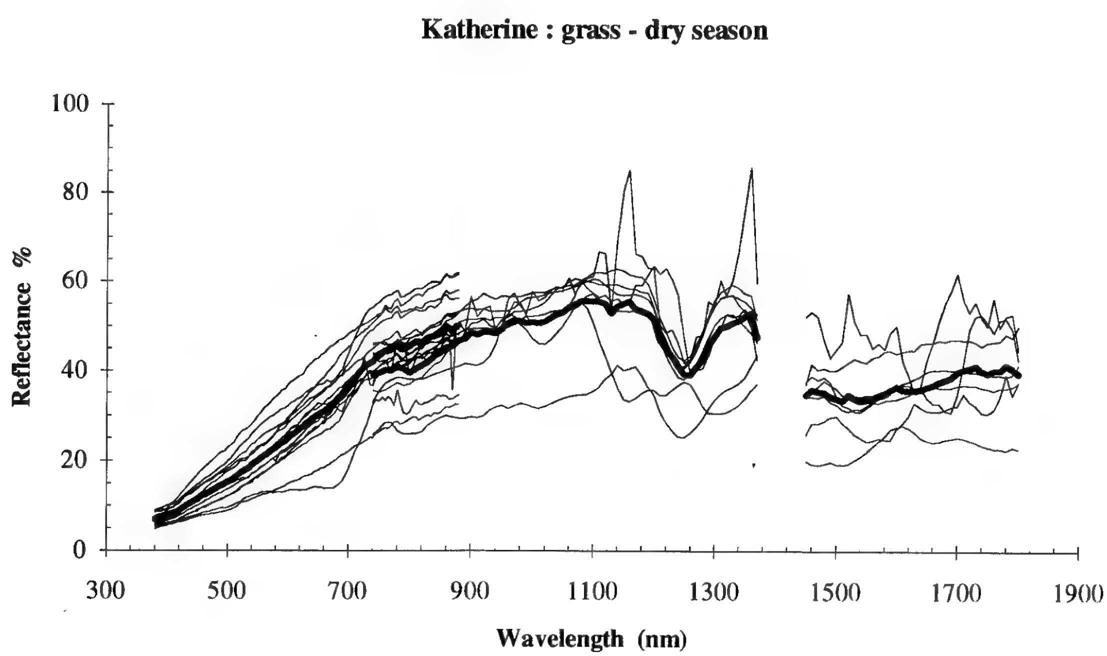
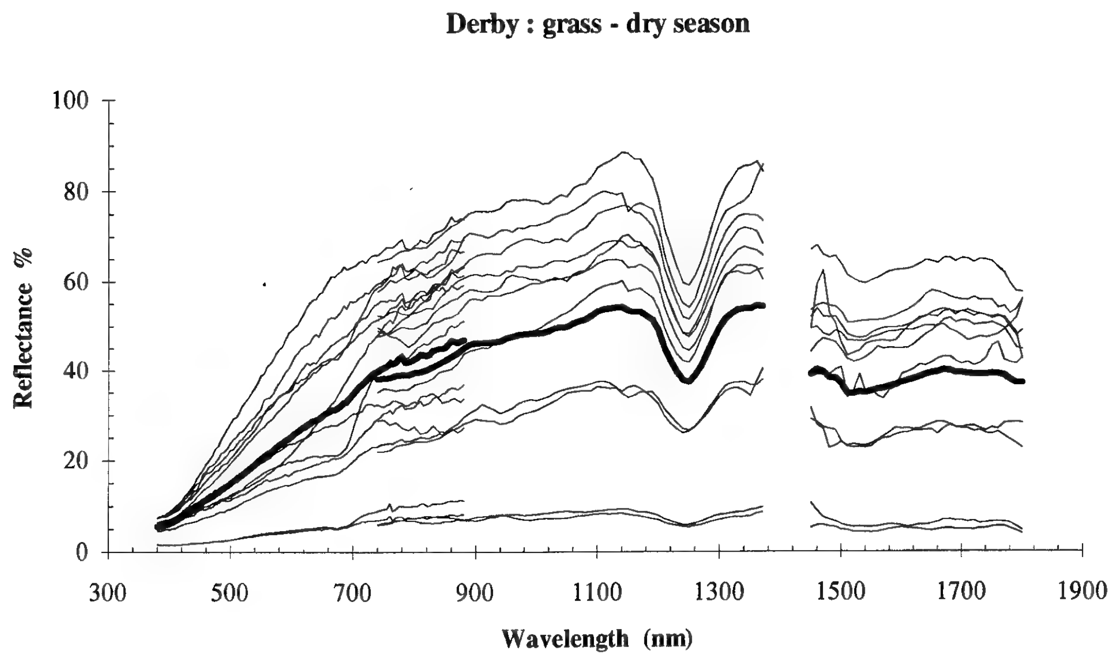


Figure 3.2 Measured reflectances of grasses in the Katherine area, NT, dry season, March 1983. The heavy line indicates the average reflectance.



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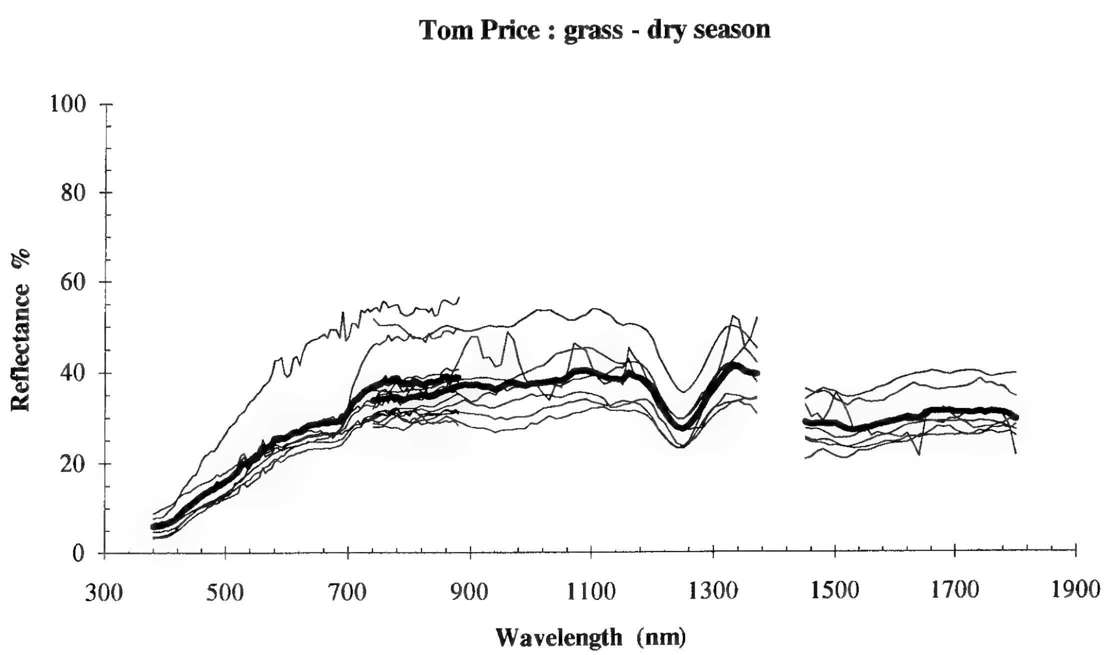

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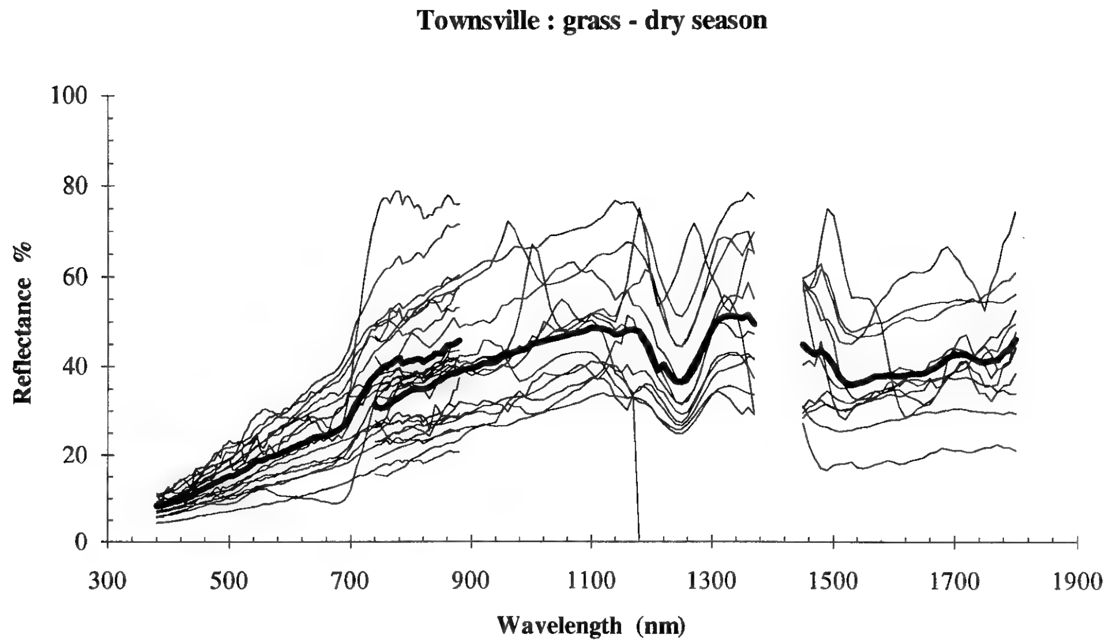

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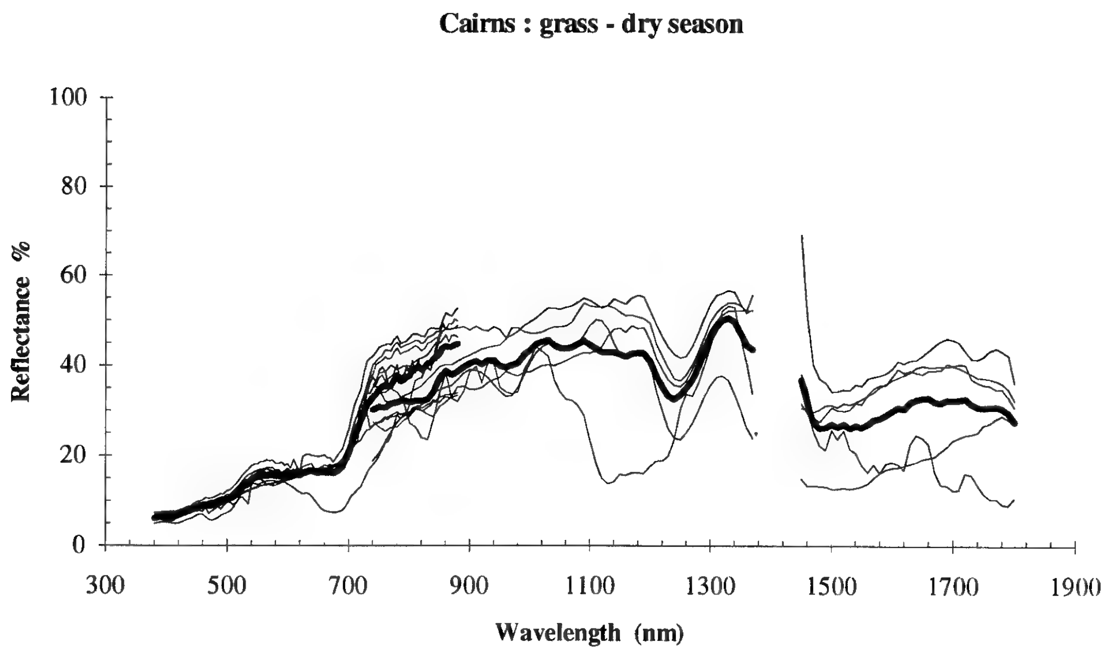

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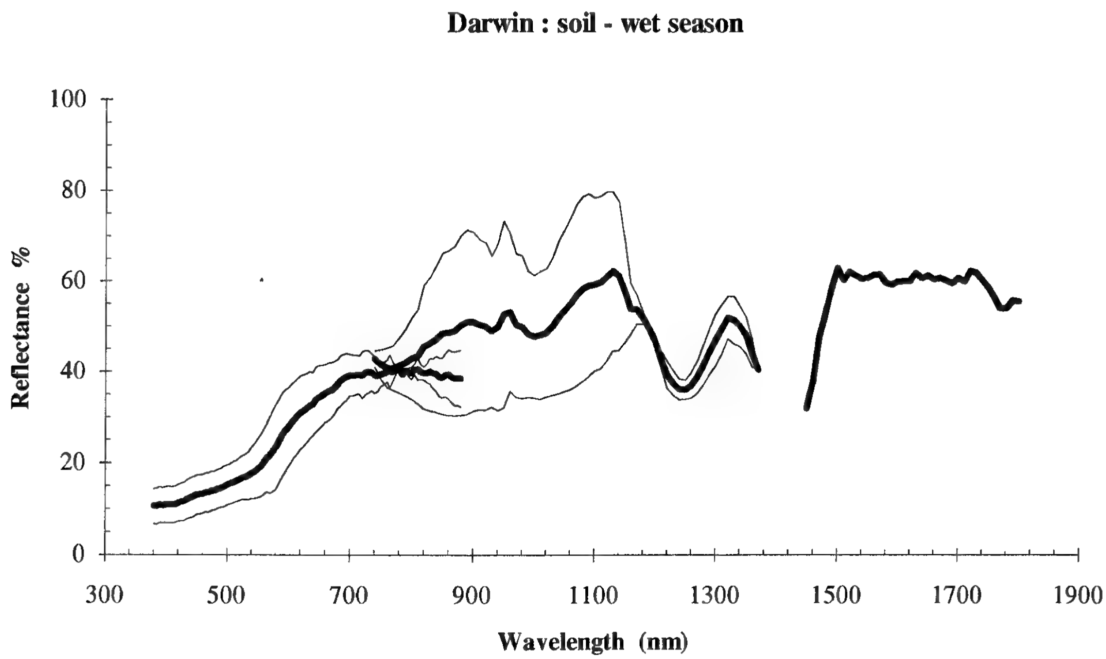


Figure 4.1 Measured reflectances of soils in the Darwin area, NT, wet season, March 1983. The heavy line indicates the average reflectance.

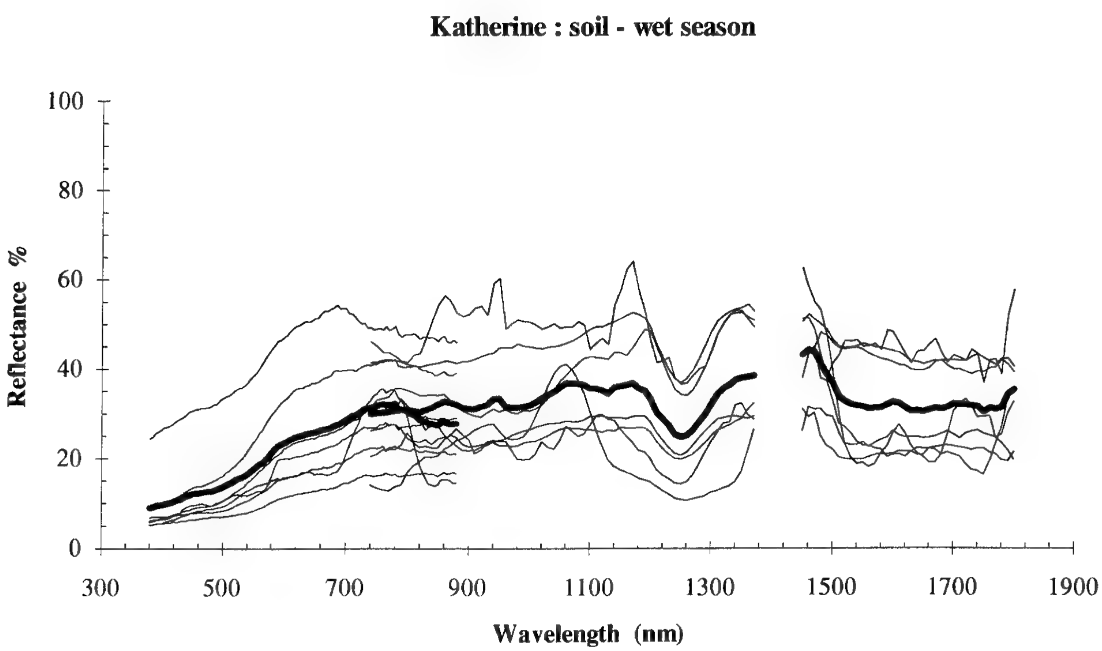


Figure 4.2 Measured reflectances of soils in the Katherine area, NT, wet season, March 1983. The heavy line indicates the average reflectance.

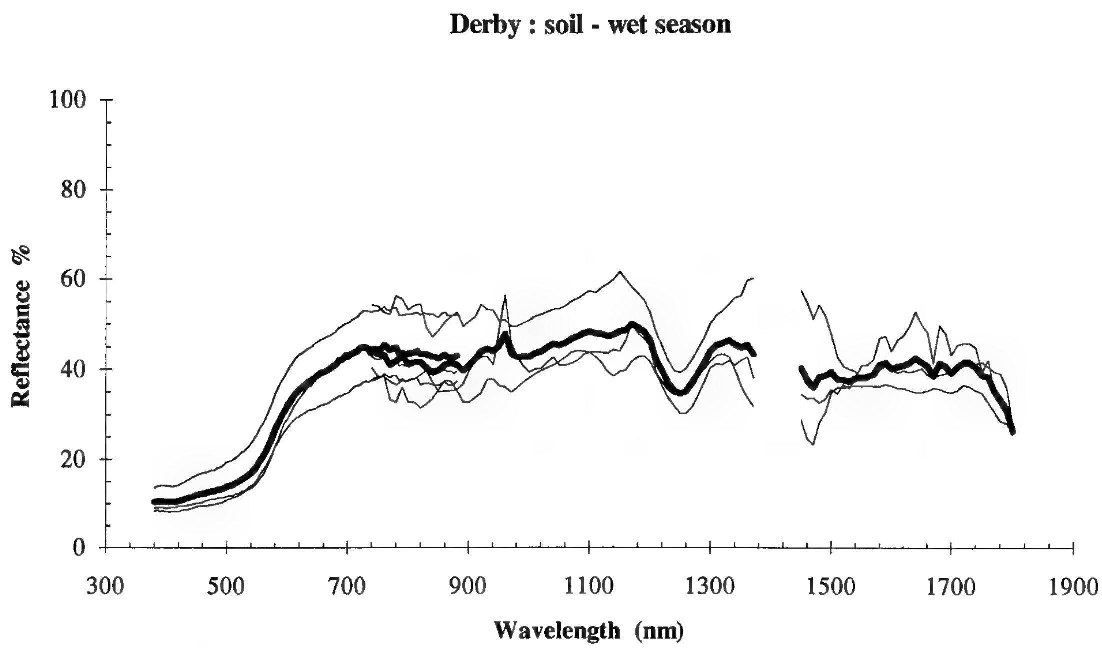


Figure 4.3 Measured reflectances of soils in the Derby area, WA, wet season, March 1983. The heavy line indicates the average reflectance.

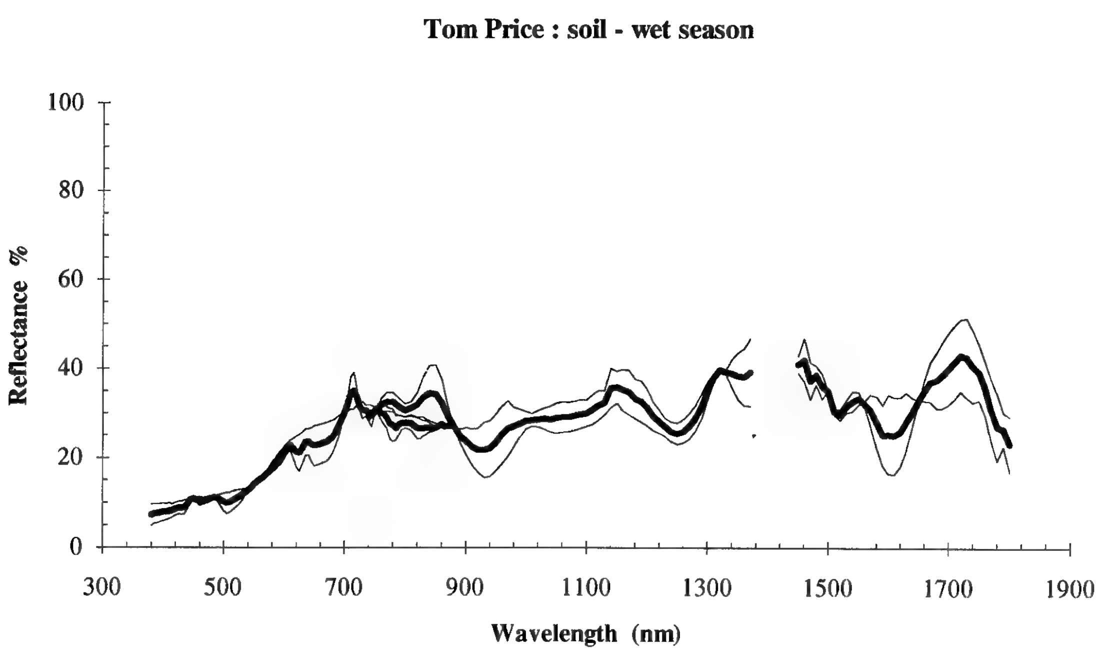


Figure 4.4 Measured reflectances of soils in the Tom Price area, WA, wet season, March 1983. The heavy line indicates the average reflectance.

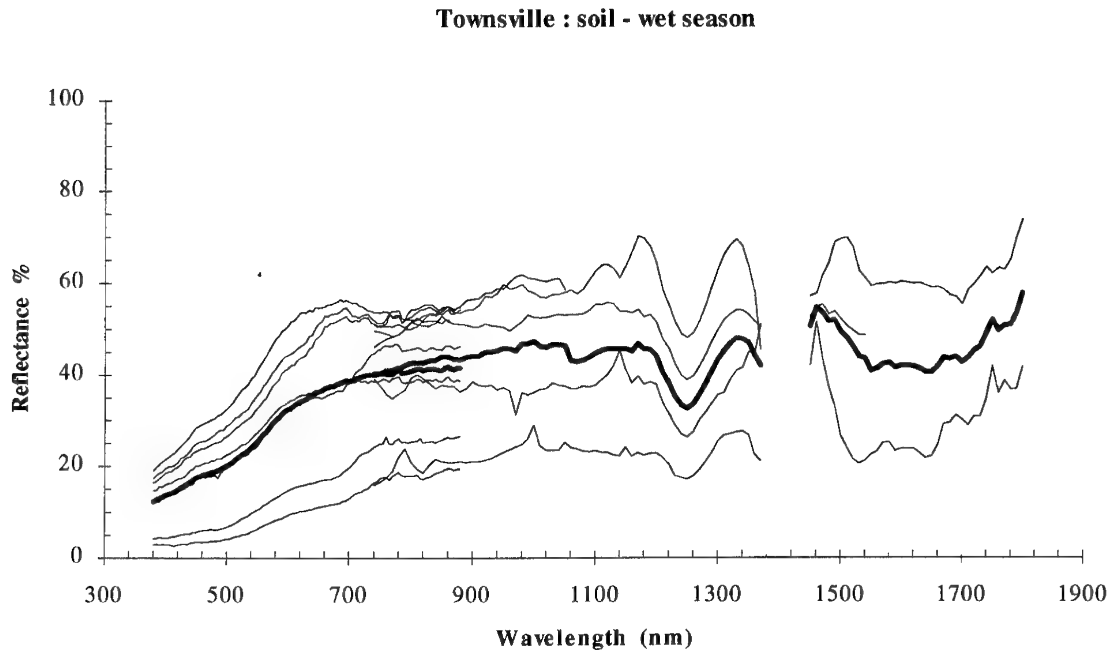
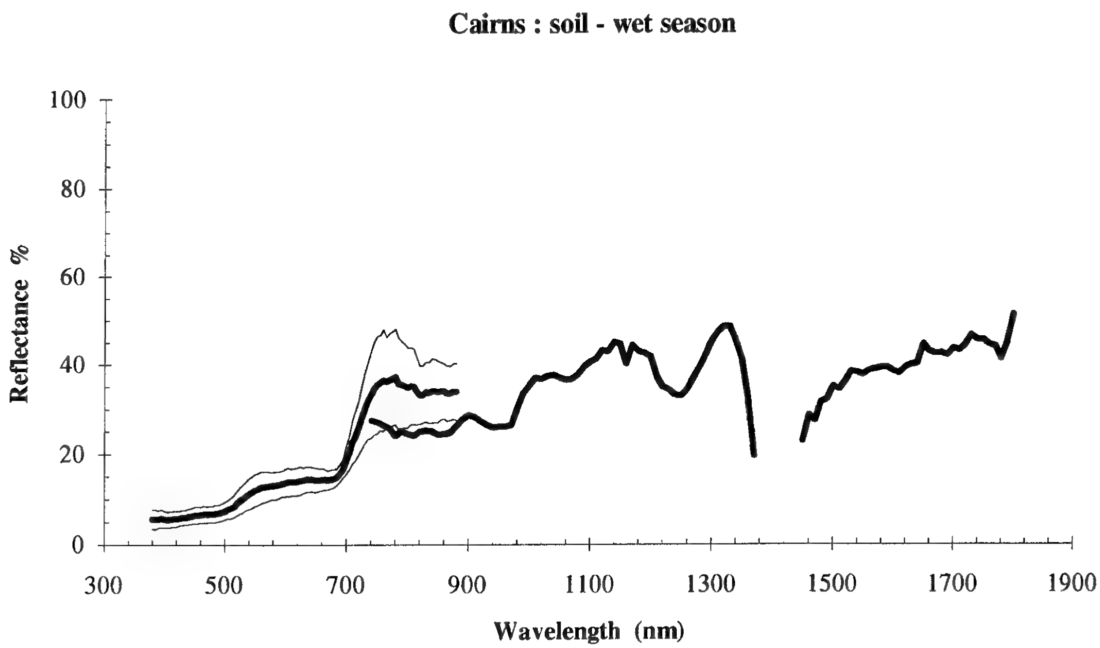


Figure 4.5 Measured reflectances of soils in the Townsville area, Qld, wet season, April 1983. The heavy line indicates the average reflectance.



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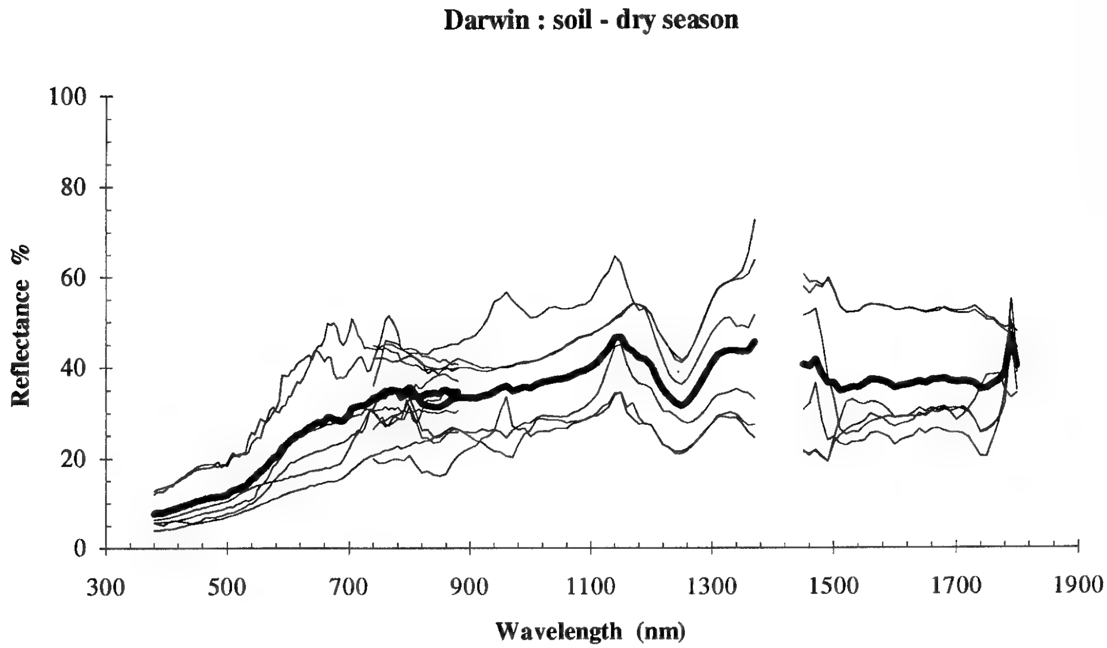


Figure 5.1 Measured reflectances of soils in the Darwin area, NT, dry season, Sept 1983. The heavy line indicates the average reflectance.

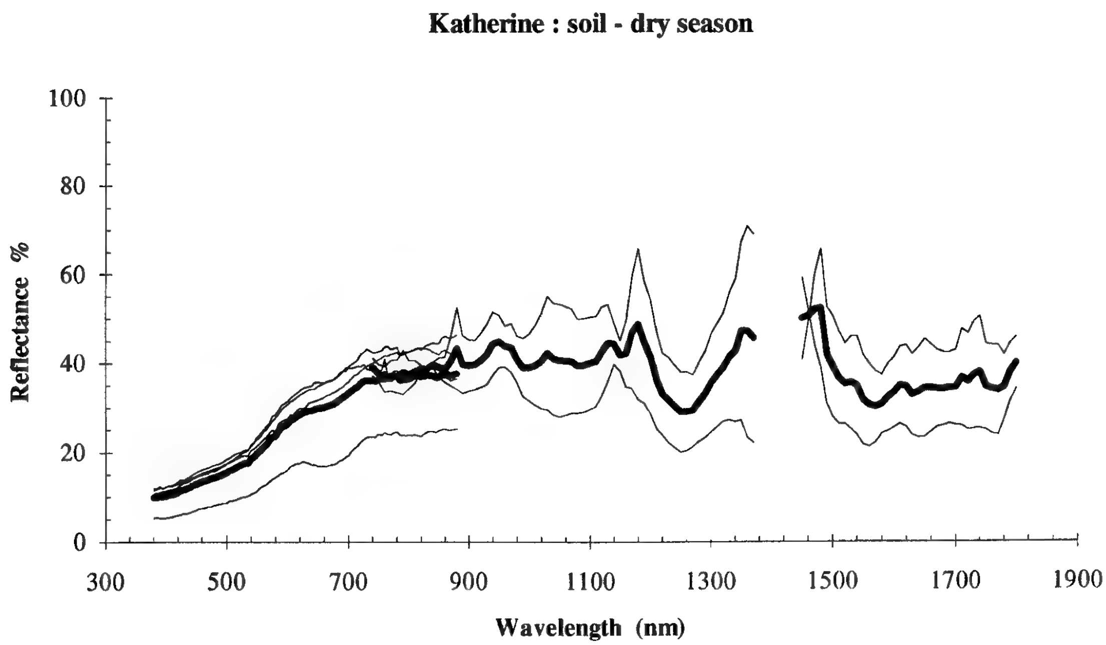


Figure 5.2 Measured reflectances of soils in the Katherine area, NT, dry season, Sept 1983. The heavy line indicates the average reflectance.

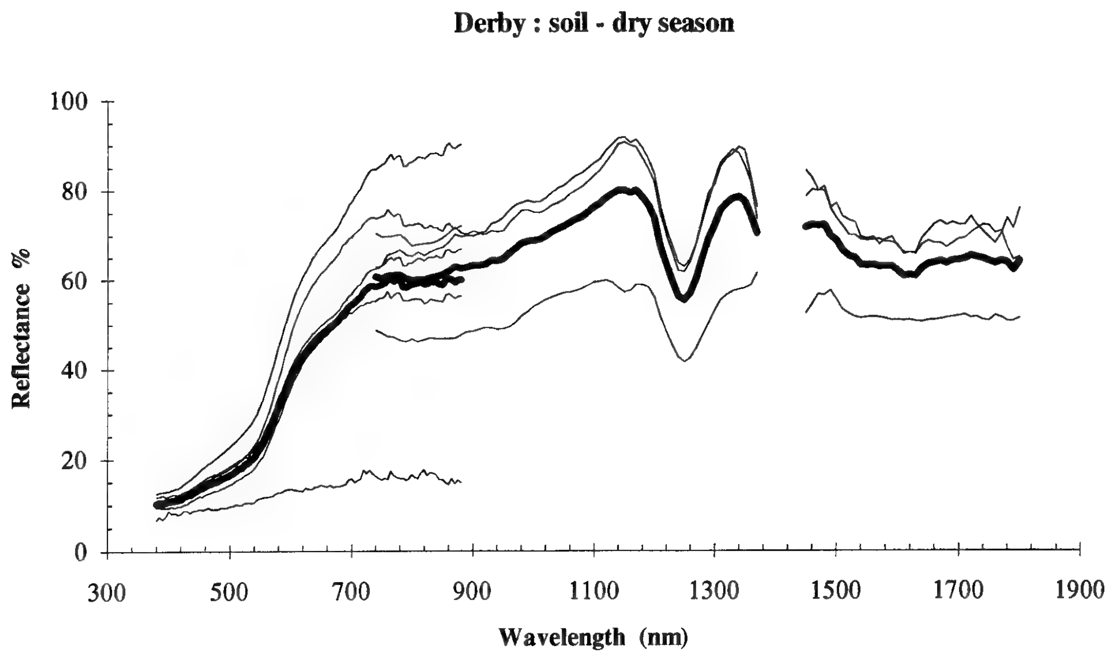
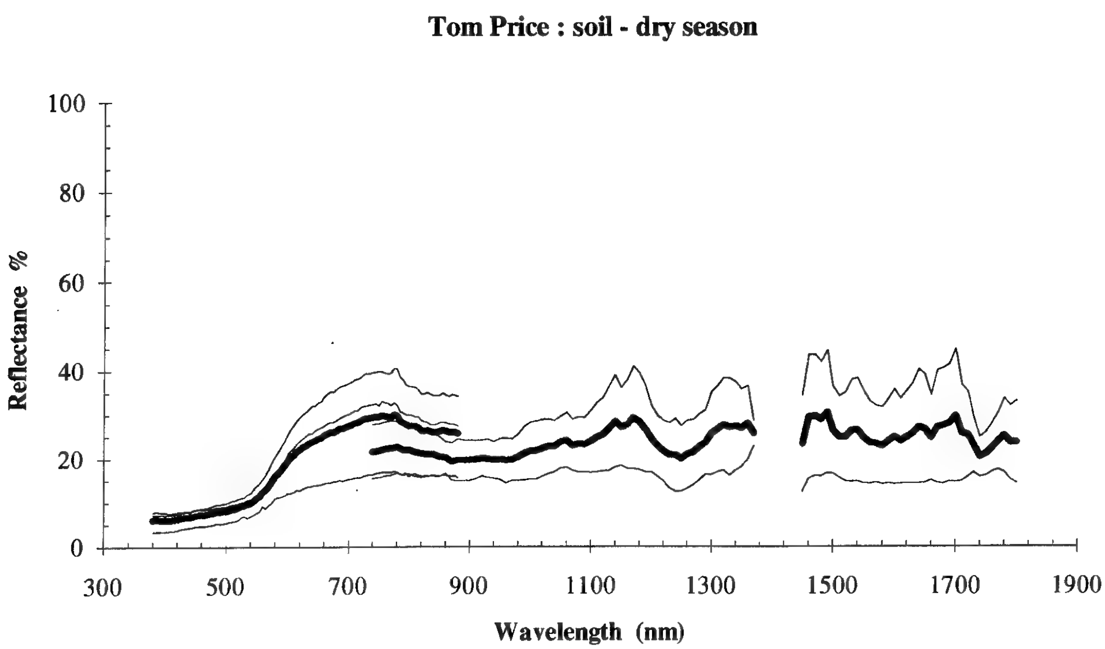


Figure 5.3 Measured reflectances of soils in the Derby area, WA, dry season, Sept 1983. The heavy line indicates the average reflectance.



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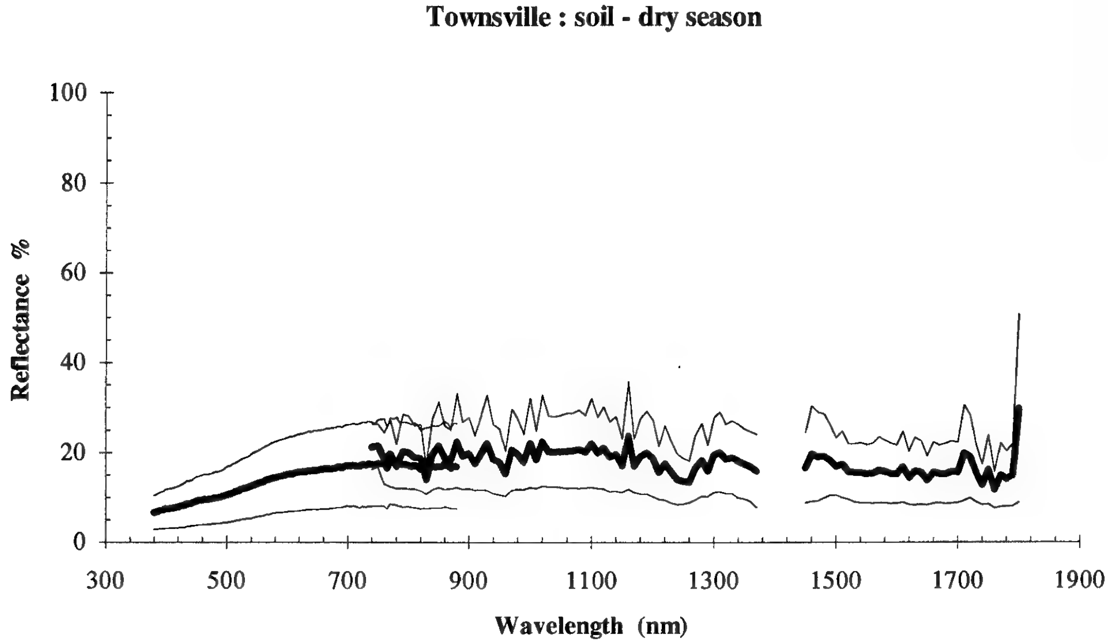

Figure 5.5 Measured reflectances of soils in the Townsville area, Qld, dry season, Oct 1983. The heavy line indicates the average reflectance.

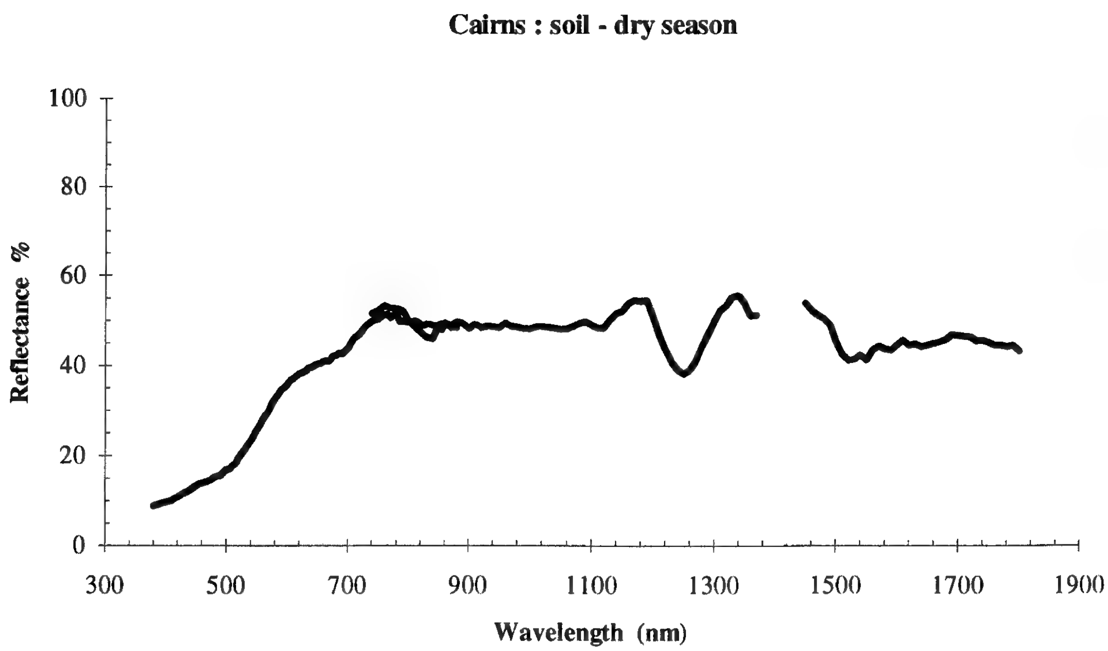

Figure 5.6 Measured reflectances of soil in the Cairns area, Qld, dry season, Oct 1983.

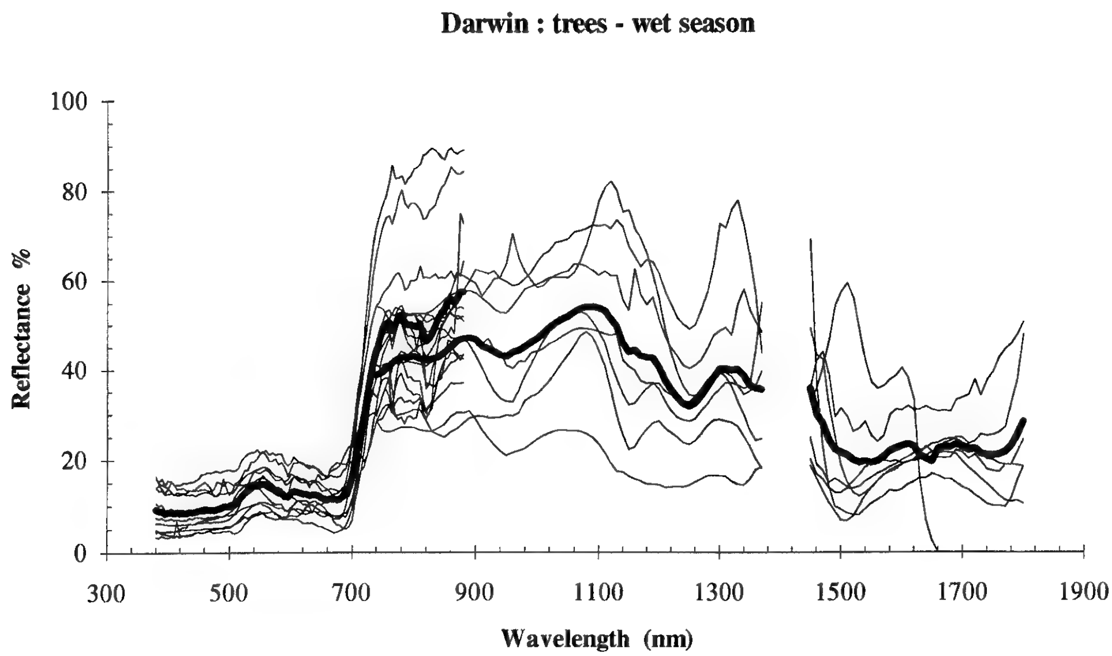

Figure 6.1 Measured reflectances of trees in the Darwin area, NT, wet season, March 1983. The heavy line indicates the average reflectance.

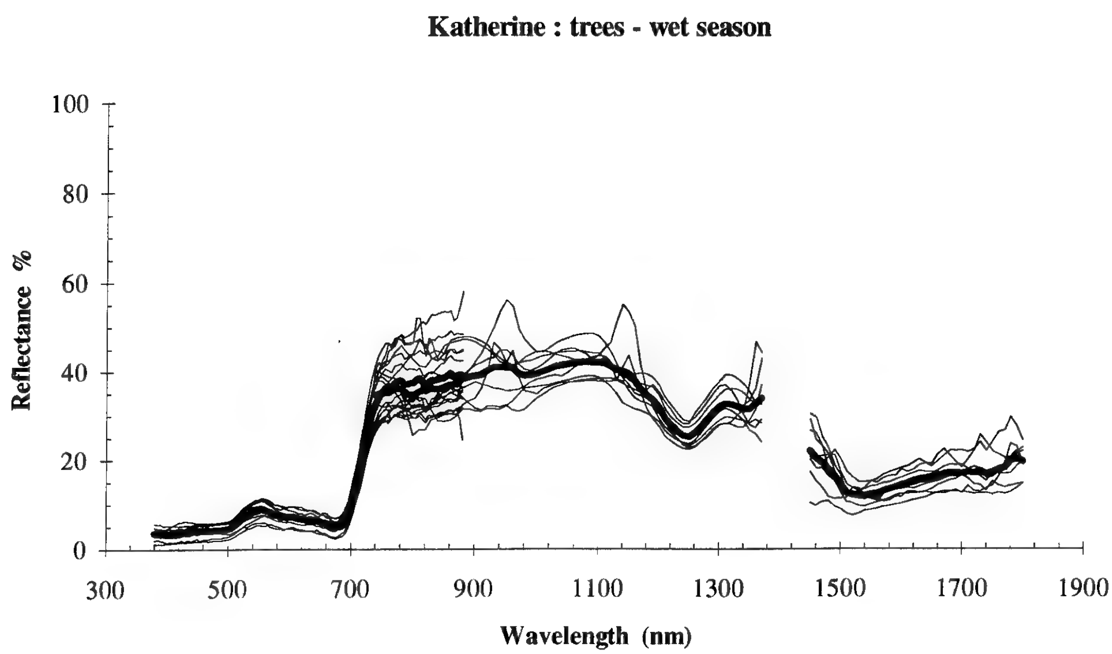

Figure 6.2 Measured reflectances of trees in the Katherine area, NT, wet season, March 1983. The heavy line indicates the average reflectance.

Derby : trees - wet season

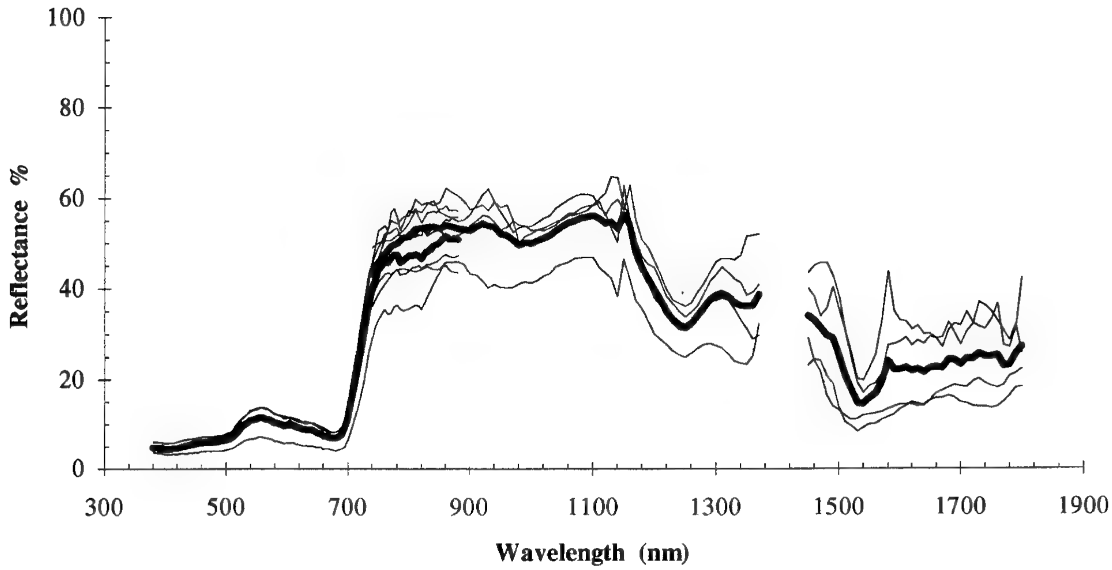

Figure 6.3 Measured reflectances of trees in the Derby area, WA, wet season, March 1983. The heavy line indicates the average reflectance.

Tom Price : trees - wet season

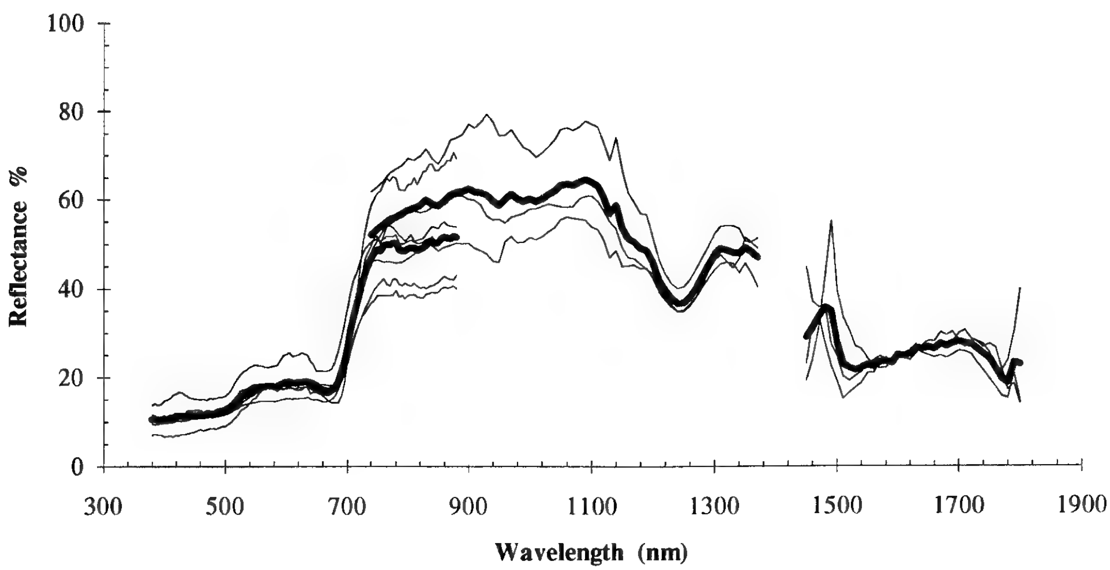

Figure 6.4 Measured reflectances of trees in the Tom Price area, WA, wet season, March 1983. The heavy line indicates the average reflectance.

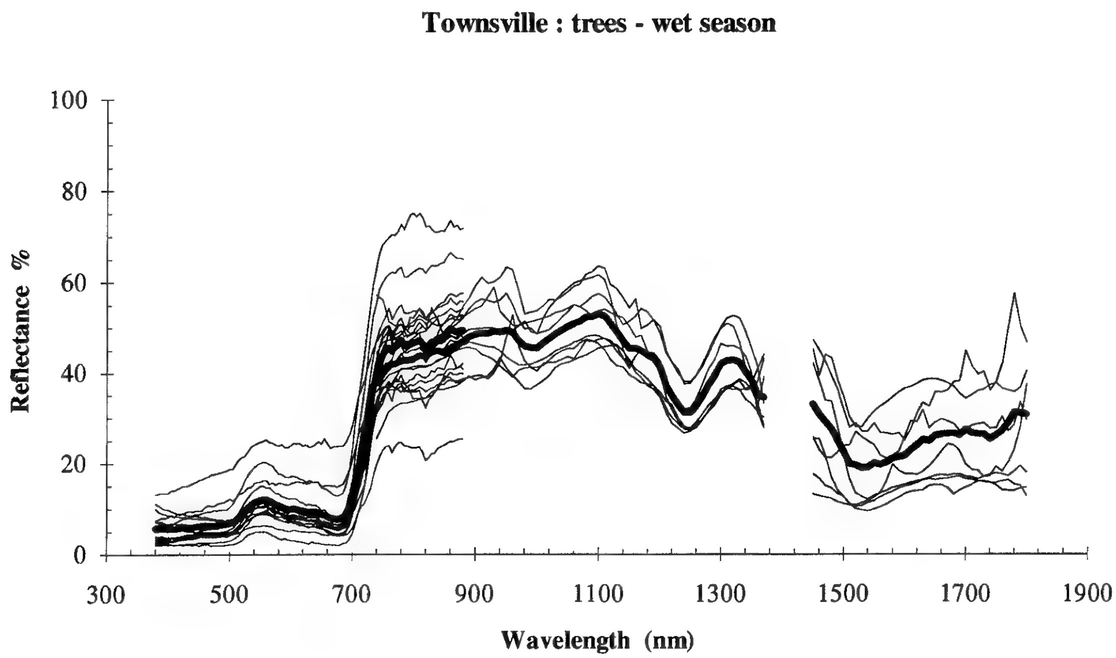

Figure 6.5 Measured reflectances of trees in the Townsville area, Qld, wet season, April 1983. The heavy line indicates the average reflectance.

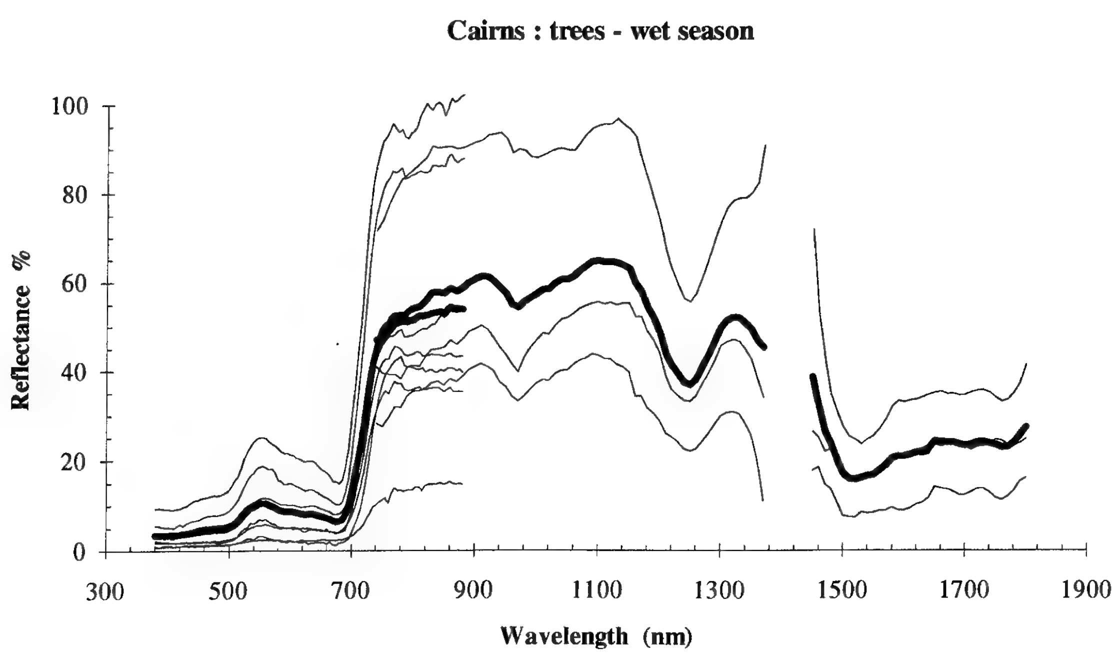

Figure 6.6 Measured reflectances of trees in the Cairns area, Qld, wet season, April 1983. The heavy line indicates the average reflectance.

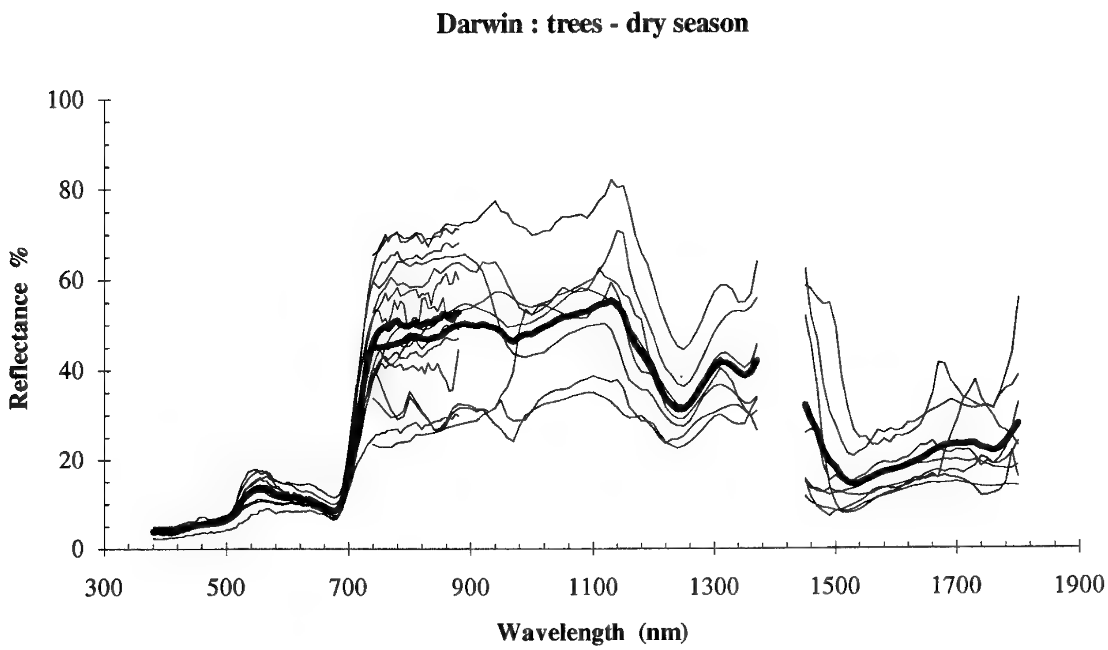

Figure 7.1 Measured reflectances of trees in the Darwin area, NT, dry season, Sept 1983. The heavy line indicates the average reflectance.

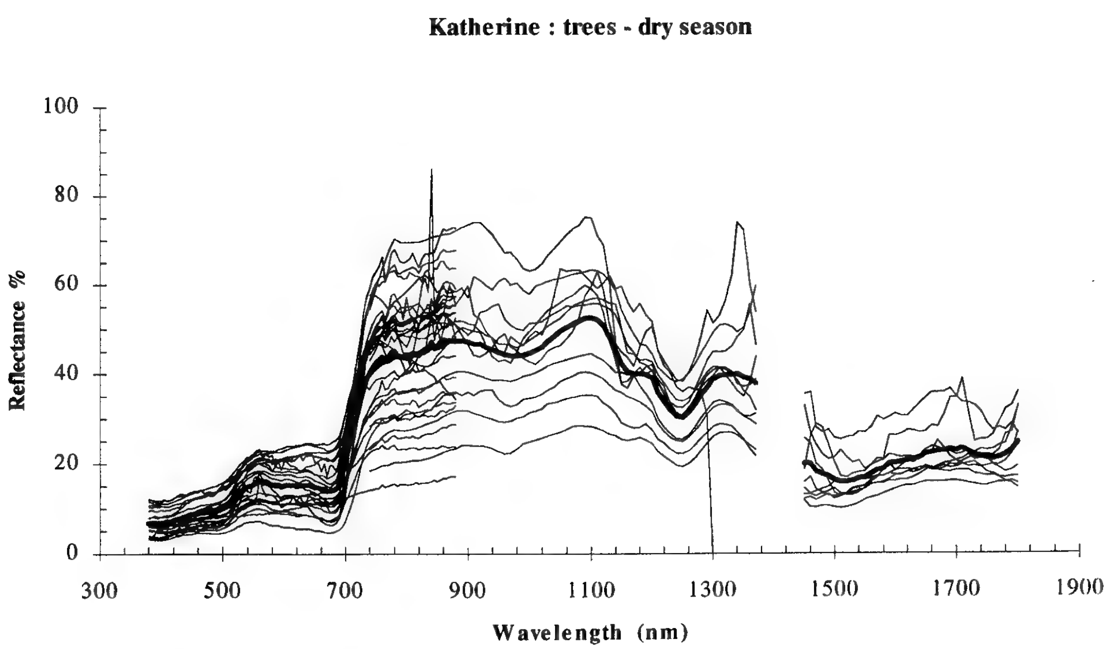

Figure 7.2 Measured reflectances of trees in the Katherine area, NT, dry season, Sept 1983. The heavy line indicates the average reflectance.

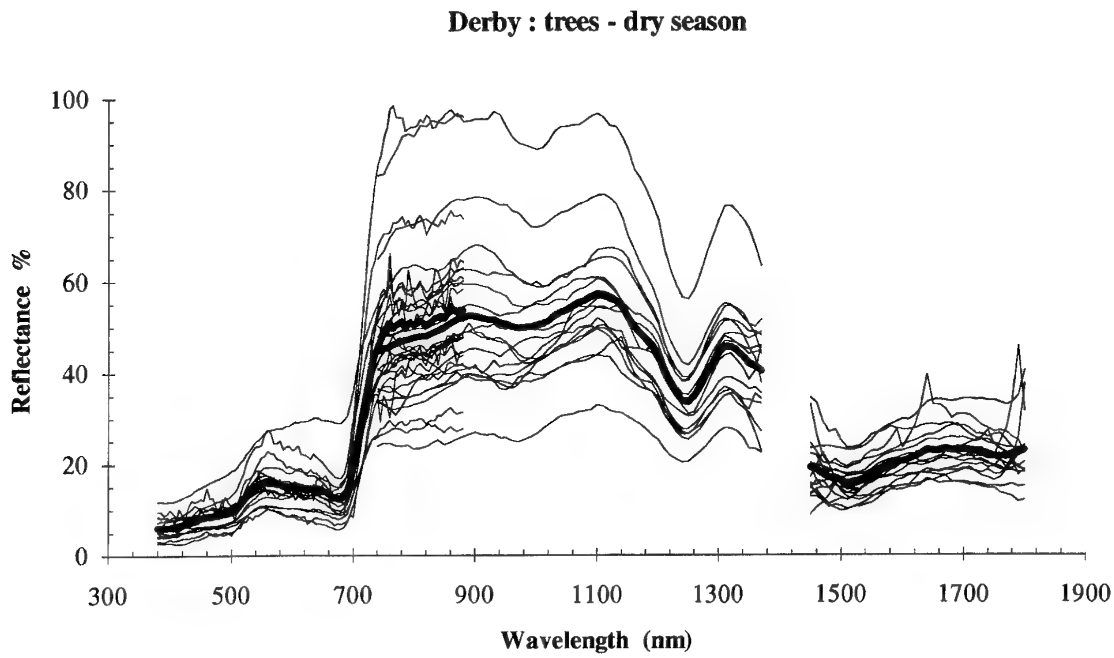

Figure 7.3 Measured reflectances of trees in the Derby area, WA, dry season, Sept 1983. The heavy line indicates the average reflectance.

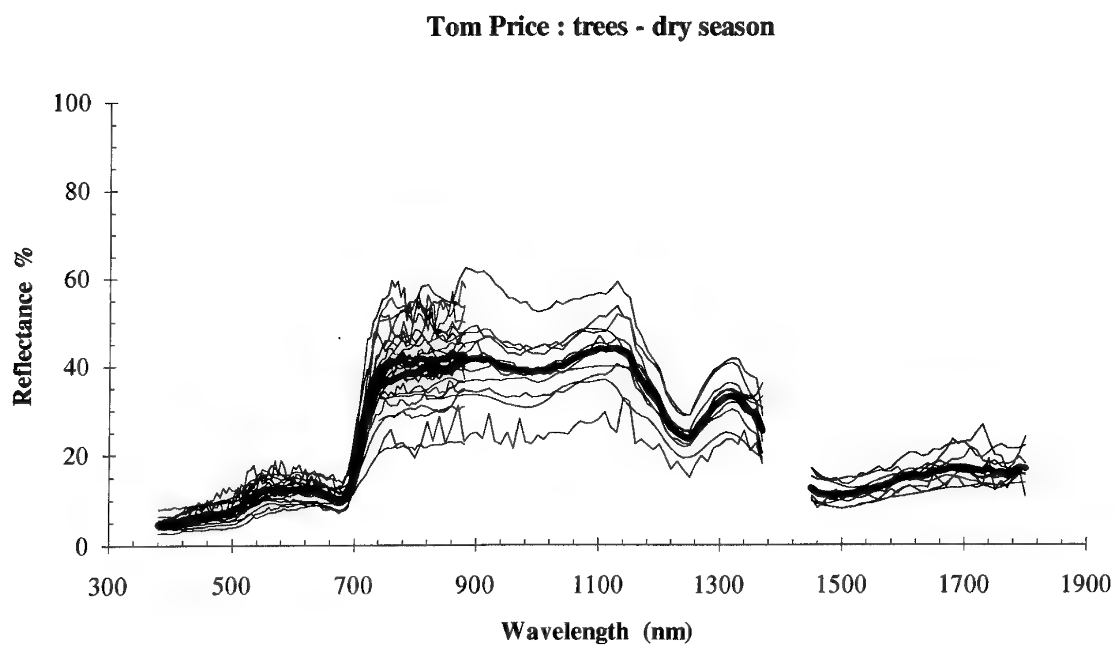

Figure 7.4 Measured reflectances of trees in the Tom Price area, WA, dry season, Sept 1983. The heavy line indicates the average reflectance.

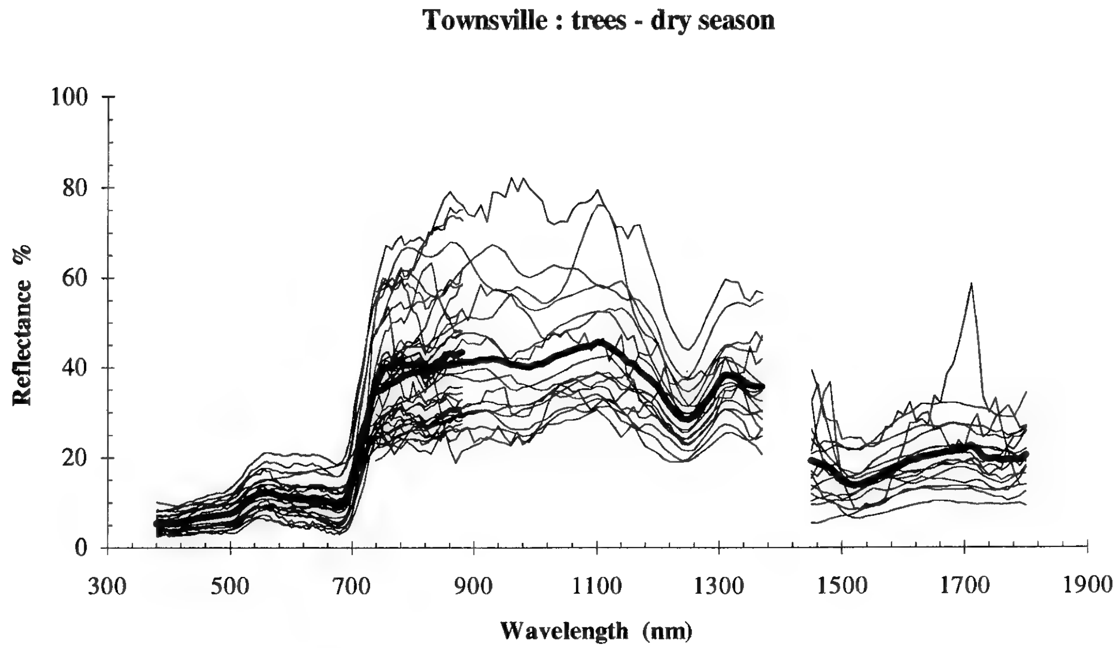

Figure 7.5 Measured reflectances of trees in the Townsville area, Qld, dry season, Oct 1983. The heavy line indicates the average reflectance.

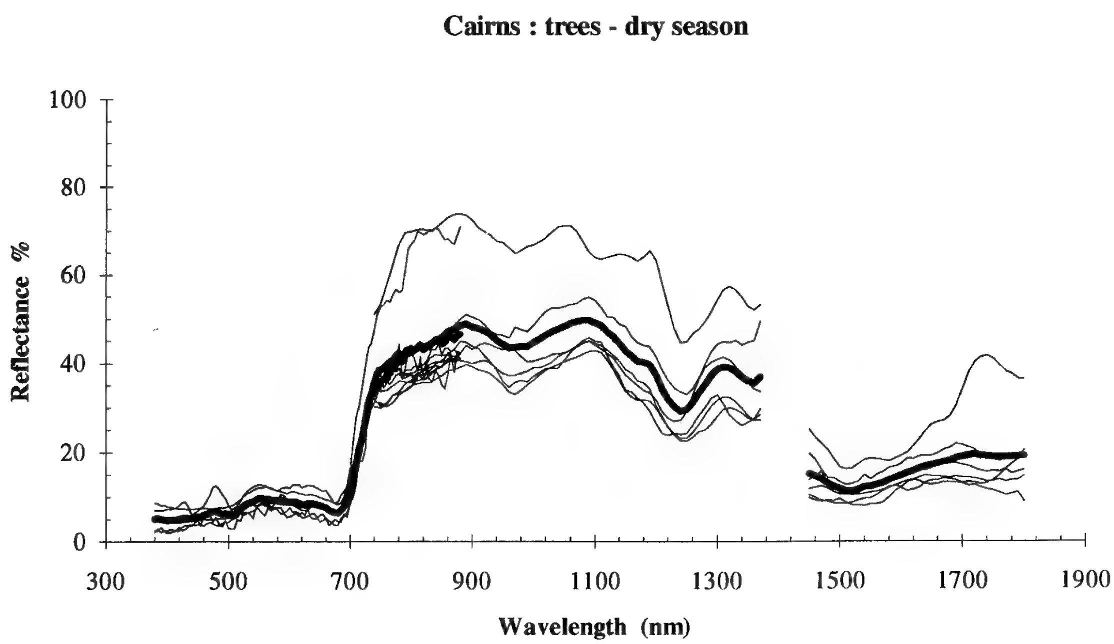

Figure 7.6 Measured reflectances of trees in the Cairns area, Qld, dry season, Oct 1983. The heavy line indicates the average reflectance.

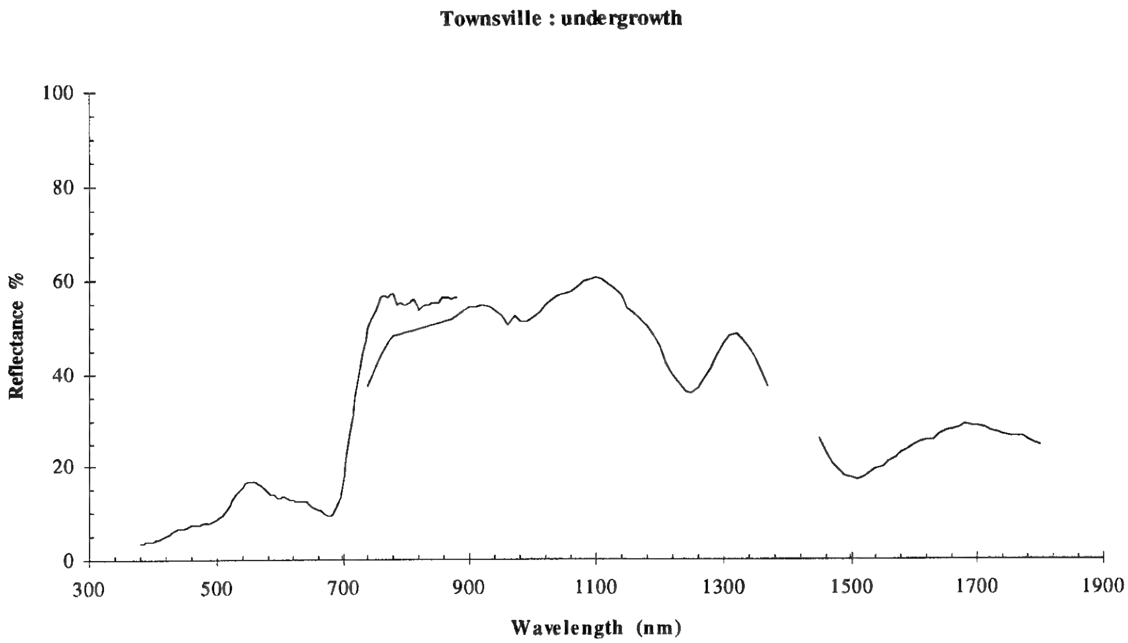

Figure 8.1 Measured reflectance of scrub/undergrowth in the Townsville area, Qld, wet season, March 1983.

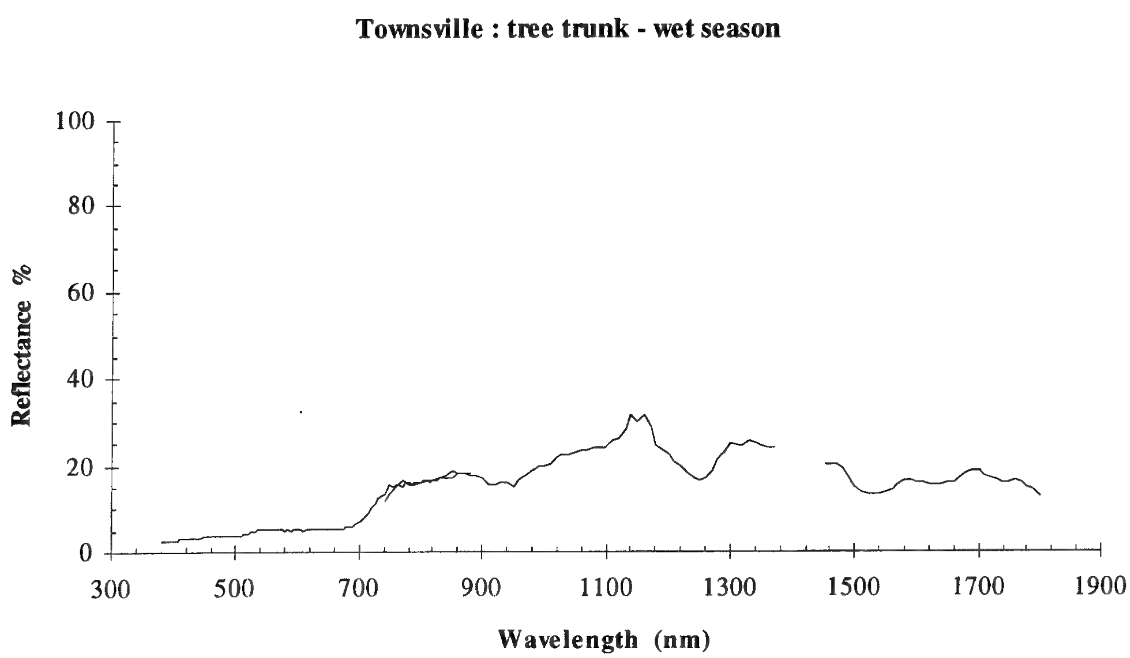

Figure 8.2 Measured reflectance of tree trunk in the Townsville area, Qld, wet season, March 1983.

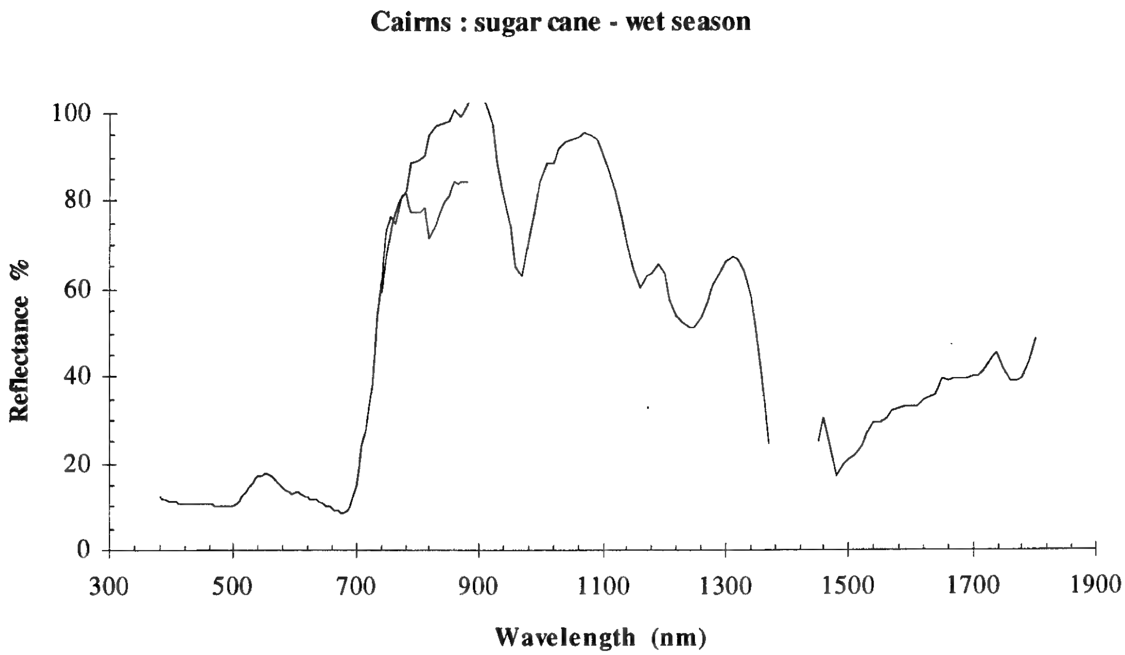

Figure 8.3 Measured reflectance of sugar cane in the Cairns area, Qld, wet season, April 1983.

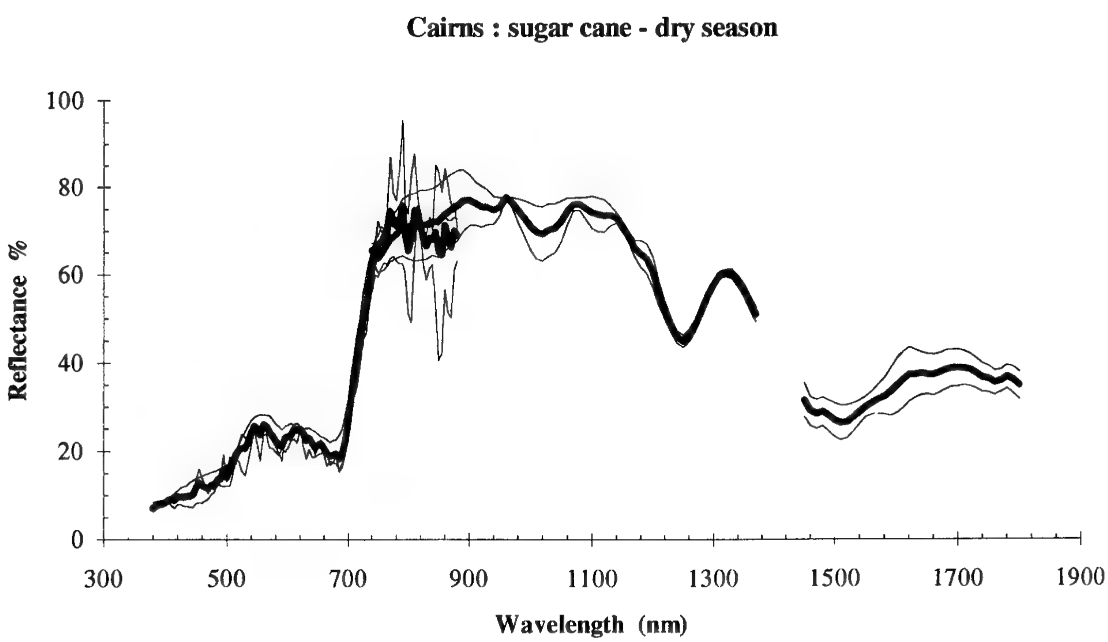

Figure 8.4 Measured reflectances of sugar cane in the Cairns area, Qld, dry season, Oct 1983. The heavy line indicates the average reflectance.

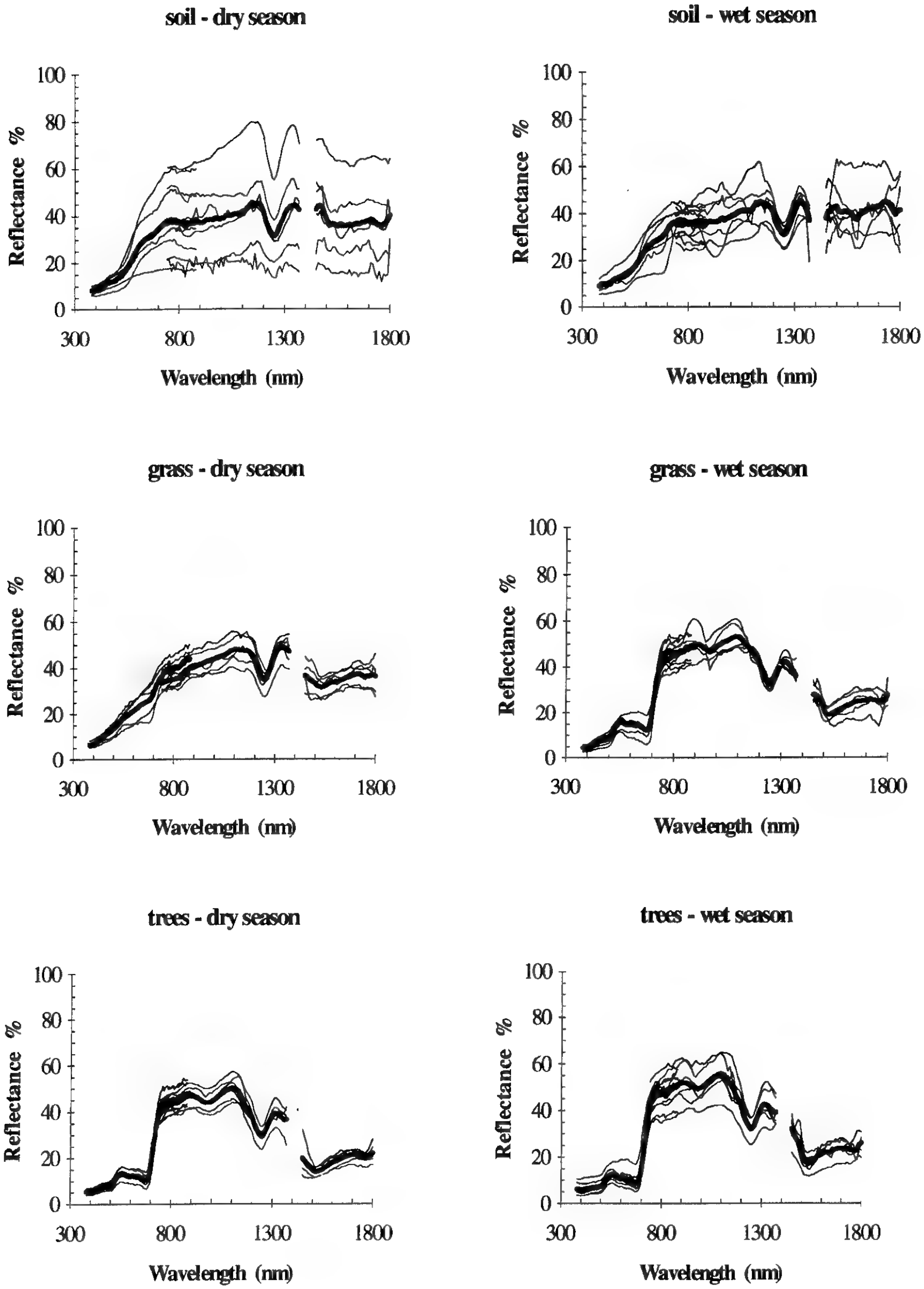

Figure 9. Compilation of all measurements showing averages across all locations shown by sample type and season.

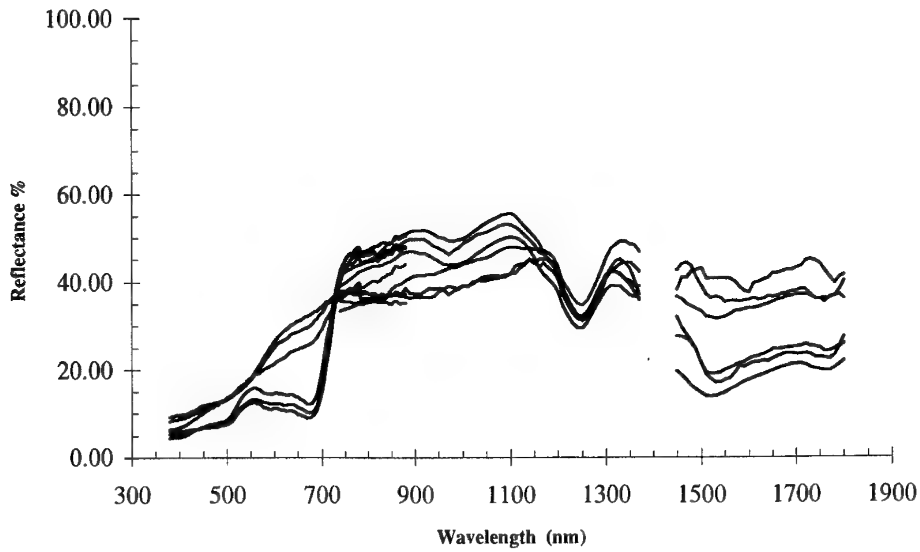

Figure 10. Spectral plots showing the average over all locations of grass, soil and trees for each season

Table 3. CIE co-ordinates calculated from averaged spectral curves.

		L*	a*	b*
Greens	grass (wet)	43.52	-3.52	20.49
	trees (dry)	40.55	-2.49	15.63
	trees (wet)	38.91	-3.9	14.19
	average	41.00	-3.30	16.77
	Paint (Aust DPP)	36.18	1.80	13.90
Tans	grass (dry)	49.57	3.44	19.04
	soil (wet)	50.43	9.68	17.16
	soil (dry)	51.02	10.8	19.66
	average	50.34	7.97	18.62
	Paint (Aust DPP)	51.84	10.40	15.00

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Appendix A: Colour Co-ordinates

Individual colours are defined in the CIE (Commission Internationale de l'Eclairage) system, with colour co-ordinates x, y, Y being calculated from a reflectance spectrum in the range 380 to 780nm using the following formulae. Colour co-ordinates are also quoted in the CIELAB co-ordinate system for ease of colour difference calculation and a more uniform colour space.

Tristimulus values: $X = k\sum_{\lambda} P_\lambda R_\lambda \bar{x}_\lambda$, $Y = k\sum_{\lambda} P_\lambda R_\lambda \bar{y}_\lambda$, $Z = k\sum_{\lambda} P_\lambda R_\lambda \bar{z}_\lambda$

Chromaticity co-ordinates: $x = X/(X+Y+Z)$ and $y = Y/(X+Y+Z)$

CIELAB:

$$L^* = 116\,(Y/Y_n)^{1/3} - 16$$
$$a^* = 500\,[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$
$$b^* = 200\,[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

where $\bar{x}_\lambda$, $\bar{y}_\lambda$ and $\bar{z}_\lambda$ are the CIE(1931) standard colour matching functions (Fig A1)
P is the relative power of a CIE standard Illuminant (Fig A2)
R is the reflectance of the sample
$k = 100/\sum Py$
X_n, Y_n and Z_n are the Tristimulus values of the reference white.

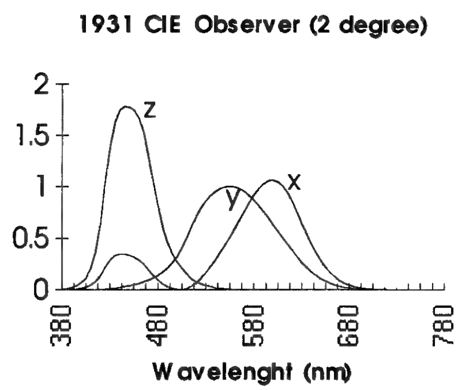

Figure A1. Colour matching functions derived from the response of the human eye as described by the CIE (1931) standard observer.

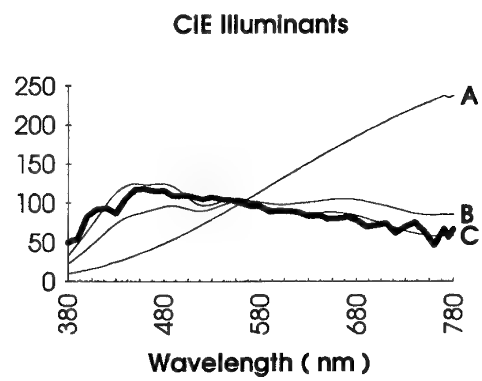

Figure A2. Relative power distributions of standard CIE Illuminants A, B, C and D65. The heavy line is Daylight (D65) which is used is the standard for all co-ordinate calculations in this paper.

Appendix B: Excel Data Sheets

All data are available as spreadsheets for Microsoft Excel (version 4 or later). Columns are clearly labelled and the main body of data show absolute reflectance values.

File names are constructed in 3 parts describing location, sample type and season as shown in the table. Hence the file KATTW.XLS describes Trees at Katherine in the Wet season.

Location		*Sample Type*		*Season*	
Townsville	TVL	Grass	G	Wet	W
Cairns	CNS	Soil	S	Dry	D
Darwin	DAR	Trees	T		
Katherine	KAT	Sugar Cane	SC		
Derby	DBY	Tree Trunk	TT		
Tom Price	TP				

Each spreadsheet (*.xls) has a pair of "Chart" buttons linked to the Macro file TSP.XLM. Clicking on either button will initiate the macro to scan the current sheet and produce the appropriate chart. The heavy line shown on the chart is the average of all values plotted. If the files are copied to another disk or directory the links between the spreadsheet and the macro files must be updated using the following procedure.

1. choose the FILE menu *(EDIT for Excel V5)*
2. select LINKS...
3. select the file TSP.XLM
4. select CHANGE .... *(CHANGE SOURCE...)*
5. choose the directory which contains the file TSP.XLM
6. select TSP.XLM
7. press OK
8. press OK again

Appendix C: Photographs of Typical Samples

Photographs of typical samples showing the area measured by the Telespectrophotometer in the frame held by the operator.

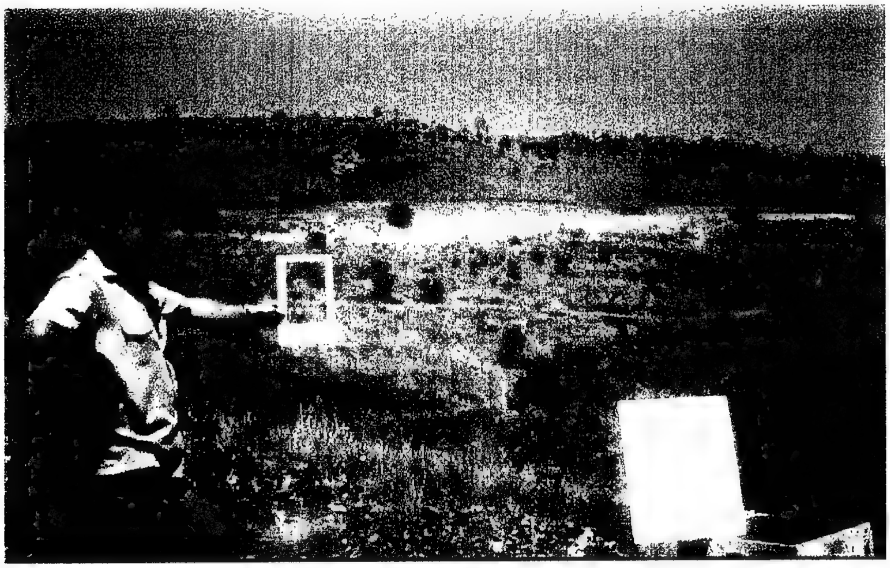

Figure C1. Typical long range measurement of Grass (spinifex) at Mt Tom Price, WA (refer TPGD.XLS, measurement no. 27-2). The white panel at the right is the Barium Sulphate reference panel.

Figure C2. Typical close measurement of Trees, Derby, WA (refer DBYTD.XLS, measurement no. 17-4).

Figure C3. Measurement of dry grass at Katherine, NT (refer KATGD.XLS, measurement no. 13-4).

Figure C4. Measurement of soil at Townsville, Qld (refer TVLSW.XLS, measurement no. 55-2).

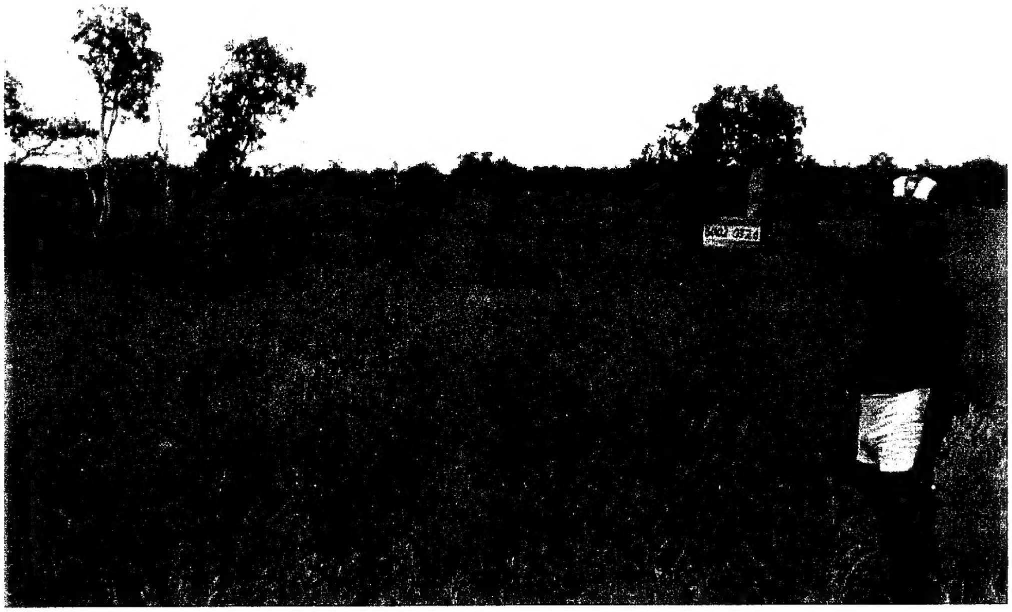

Figure C5. Measurement of wet season trees at Derby, WA (refer DBYTW.XLS, measurement no. 35-2).

Figure C6.

Wet season measurement site at Darwin showing 2m tall spear grass and post bushfire regrowth.

COLOURS OF NORTHERN AUSTRALIA:
VISIBLE AND NEAR-IR REFLECTANCE OF NATURAL TERRAIN ELEMENTS

Russell J. Boyd

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19. Abstract

A major requirement of the systematic design of camouflage is to obtain a colorimetric match of the camouflaged object to its anticipated surroundings. This match needs to cover both the visible and, because of the operating bands of silicon based surveillance sensors such as image intensifiers and low light TV, the near-infrared. This report presents spectral reflectances and CIE colour co-ordinates of natural terrain elements in the visible and near-infrared wavelengths (380 - 1800nm). Measurement sites range from Townsville to Tom Price across northern Australia. Complete data sets are available as Microsoft Excel spreadsheets and charts.